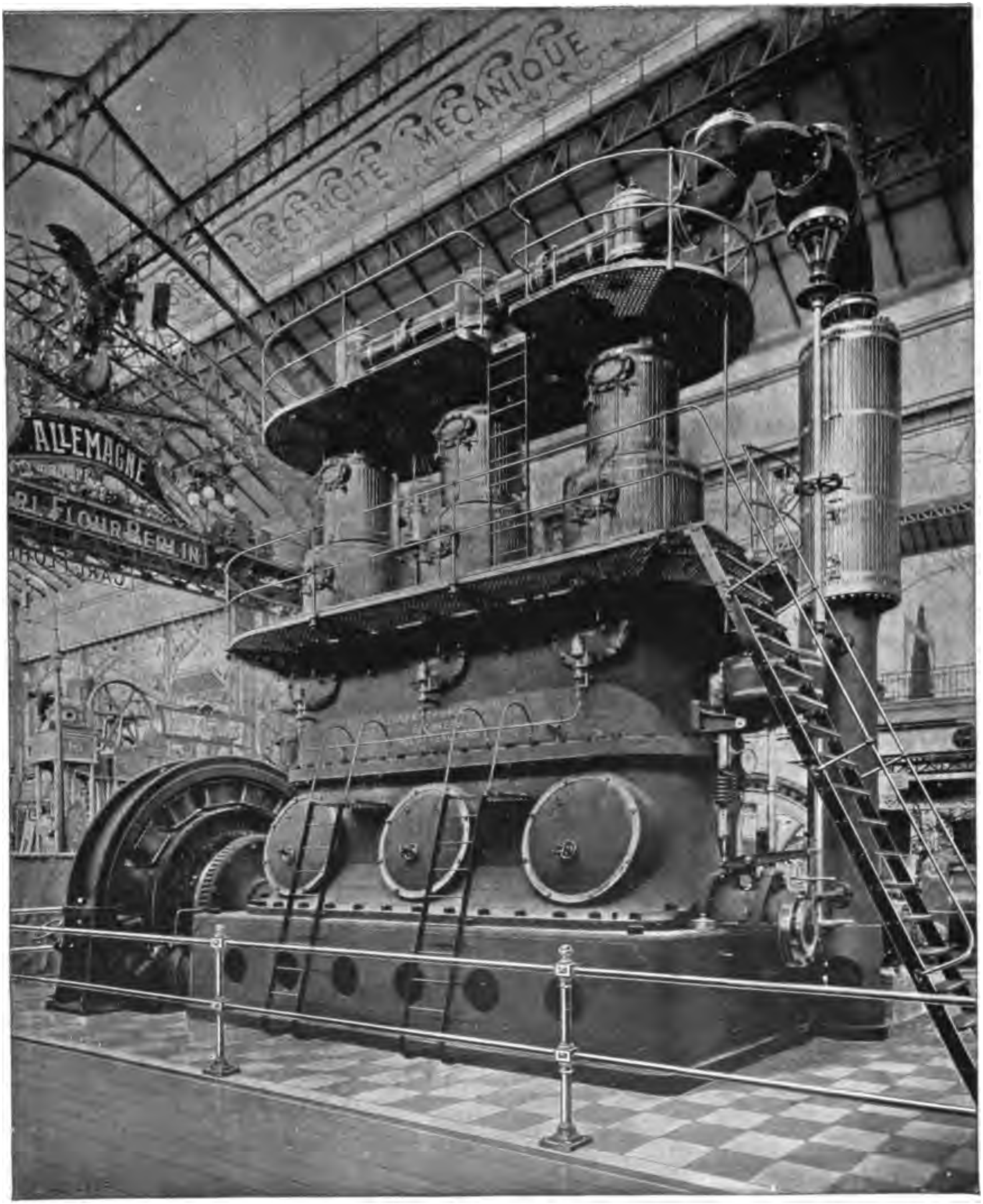
ELECTRICAL INSTALLATIONS

ELECTRICAL INSTALLATIONS



Frontispiece

WILLANS & ROBINSON TRIPLE-EXPANSION SINGLE-ACTING ENGINES

ELECTRICAL INSTALLATIONS

OF

ELECTRIC LIGHT, POWER, TRACTION AND INDUSTRIAL ELECTRICAL MACHINERY

BY

RANKIN KENNEDY, C.E.

AUTHOR OF "ELECTRICAL DISTRIBUTION BY ALTERNATING CURRENTS," "PHOTOGRAPHIC AND OPTICAL ELECTRIC LAMPS," AND NUMEROUS SCIENTIFIC ARTICLES AND PAPERS

IN FOUR VOLS.

WITH NUMEROUS DIAGRAMS AND ILLUSTRATIONS

VOL. III.—THE PRODUCTION OF ELECTRICAL ENERGY, PRIME MOVERS, GENERATORS AND MOTORS

LONDON: THE CAXTON PUBLISHING CO.

1902

Printed by BALLANTYNE, HANSON & CO.
At the Ballantyne Press

PREFACE TO VOL. III

THIS volume takes up the survey of the several prime movers employed to convert heat energy into electrical energy, the heat engine combined with a dynamo-electric machine being at present the only commercial generator of electric pressures. The dynamo-electric machine is popularly called a generator or a motor; but, strictly speaking, it is neither, for a dynamo without a prime mover is no generator, and the motor only receives the power of some prime mover and passes it on to a machine to be driven. Hence, knowledge of the engines employed to furnish the power is of the utmost importance in the electrical engineer's education. The difference between the electrical engineer and the electrician may be said to consist chiefly in this, that the electrical engineer must be a steam and mechanical engineer with some knowledge of electricity and magnetism, while the electrician need not have any knowledge of steam and mechanics; but he should have a profound knowledge of electricityand magnetism, electro-dynamics, electrolysis, insulation, instruments, and measurements. And the sooner this distinction is made the better, for many men find, and are disappointed, that in practice few electricians are required, while many electrical engineers are necessary. This volume is written for the electrical engineer; the electrician must go farther in other works treating fully of magnetism and electricity only.

Few electrical engineers are called upon to design dynamo-electric machinery; but nevertheless some knowledge of their design is necessary, and therefore special methods, making the design easily comprehensible, are given herein for various classes of machines, continuous current and polyphase.

For many of the excellent illustrations in this volume, thanks are due to the various firms who have kindly lent their blocks for use.

RANKIN KENNEDY.

LEEDS, *November* 1902.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

LIST OF FULL PAGE PLATES

ELECTRICAL INSTALLATIONS

CHAPTER I

ACCUMULATORS IN INSTALLATIONS

THE economical storage of electrical energy is one of the great unsolved problems in electrical engineering. The batteries at present in the market are useful—in fact so useful that, despite their many drawbacks, low efficiency, and high cost, they have a considerable field of successful operation. The electrical engineering industry would be immensely benefited by any system of storage as cheap, efficient, and simple as that employed in storing gas or water.

The problem has been attacked by many able electricians and chemists, and money spent upon it lavishly; but the result is not by any means commensurate with labour and money spent upon the pursuit. And yet we should not be discouraged, nor should experimenters and inventors be discouraged, as they too often are, especially in the so-called scientific press of Great Britain. Improvements are mostly made by very slight successive advances, difficult often to recognise as improvements. No invention has ever been made of anything whatever by one great master-stroke of genius. The popular idea that one man invented the steam-engine, another man the electric telegraph, another the dynamo, another the telephone, is firmly fixed in the mind of the ordinary man; but it is a very much mistaken idea. Not one man but dozens have been engaged in the improvements which at last succeeded in success. James Watt made the steam-engine a success; but many clever men had built and run steam-engines before Watt, and Watt began where they left off. His first introduction to a steam engine was gained in his capacity as a mechanician, when a model engine was given to him for repairs. Watt's labours made the steam-engine more perfect, and it became a commercial success, and hence the popular fallacy that Watt invented the steam-engine.

And so with all inventions. The telephone, in all its principles, was the result of many small advances made by men before Graham Bell's time. Phillip Reiss had made and exhibited telephones requiring but slight improvements to make them successful. Bell

took up the thread where it was left broken by Reiss, and made the improvements which introduced it at once as a commercial success. And so, if we examine the history of all inventions, it is always the case—some one gets it on the verge of success, puts the finishing touches upon it, and the public jump to the conclusion that this inventor originated the whole thing from his own inner consciousness, whereas he was only one of many who had laboured to produce the invention. For these reasons it is better to receive improvements, however small and apparently insignificant, with a good deal of charity, and rather overrate them than underrate their value.

The electric accumulator was early invented, or rather discovered. Ritter, a German, first made a definite enunciation of the lead accumulator. It had been known that in an electric decomposition cell, when it had been used in the decomposition of an acid solution in water with platinum electrodes, that the electrodes had become charged, and would give back some current after being disconnected from the battery; and it was proved that the current was due to oxygen adhering to the anode, and hydrogen adhering to the cathode. These gases are, in fact, to some extent occluded in the electrodes when decomposition is going on. This, then, was the beginning of the accumulator. Ritter discovered that lead plates gave better results. M. Planté, a French chemist, made a thoroughly exhaustive research on the lead cell, and discovered that, by a process of charging, discharging, and reversal of the electrodes, plates forming the anode and cathode could be transformed—the anode into a porous peroxide of lead, and the cathode into porous, spongy, metallic lead, capable of receiving and giving out a charge of large quantity; that is to say, Planté's plates were by his process made of large capacity for electrical energy. Planté discovered nearly all that is known about treating lead plates to form them into battery plates of large capacity. The plates must be pure lead without any alloy, and should be annealed in high pressure steam or hot air, then put into a solution of water with 5 per cent. of commercial nitric acid. This bath should be kept hot, nearly boiling, and the plates cooked for twelve to sixteen hours in it. They are then to be allowed to dry naturally in the air, and are then put into the battery boxes, in groups of plates to form the anodes and cathodes, in a solution of sulphuric acid and water 1200 sp.g. Twaddle, and slowly charged and discharged. Long slow charging and discharging, with frequent reversals of current, gradually converts the lead, which has been rendered somewhat spongy by the acid bath, into a still more porous condition, and forms, on charging, a thick coating of lead oxides on the anode and a thick coating of spongy lead on the cathode.

The whole of the chemical action involved in the accumulator cell, when discharging or charging, is not very well understood.

The discharged Planté plates may be considered. The plate which is attached to the positive pole or conductor of the dynamo, during charging, is called the positive plate, or anode; while the other plate, attached to the negative pole, is the cathode or negative plate. Of course, in discharging, the current reverses, for it flows from the negative plate through the liquid to the positive plate in discharging.

The discharged negative plate is found coated with a mixture of lead oxide, Pb,O, and sulphate, Pb,SO_4, and the positive plate with PbO, and some higher oxides.

On charging, the water is decomposed, hydrogen appearing at the negative plate and oxygen at the positive plate. The hydrogen combines with the sulphate of lead, thus:—

$$PbSO_4 + H_2 = Pb + H_2SO_4,$$

forming sulphuric acid, so that, if we keep a hydrometer in the cell, it will gradually rise, showing that the liquid is becoming of a higher sp.g. as the charge goes on, until a point is reached at which the whole $PbSO_4$ is decomposed, the Pb being left on the plate in a very finely subdivided powdery state.

This is the main action, but any oxide PbO on the plate is also decomposed, forming water, thus:—

$$PbO + H_2 = Pb + H_2O,$$

this, however, is not of great amount, otherwise the solution would not increase in density.

At the positive plate the oxygen combines with the low oxides there, producing higher oxides, principally peroxide, PbO_2, and, very probably, a higher oxide, and any sulphate formed on the positive, during discharge, will be oxidised also, thus:—

$$PbSO_4 + O + H_2O = PbO_2 + H_2SO_4.$$

This action, it will be observed, also tends to increase the density of the solution during charging.

These actions are reversed during discharge, the finely divided metallic lead on the negative plate combines with the oxygen in the solution again and with the sulphuric acid, thus:—

$$(1)\ Pb + O = PbO, \text{ and}$$

$$(2)\ PbO + H_2SO_4 = PbSO_4 + H_2O,$$

and the oxide on the positive plate combines with the hydrogen, forming water, thus:—

$$H_2 + PbO_2 = H_2O + PbO,$$

and also sulphate, according to equation 2; when the cell is discharged to a very low degree this sulphate forms in too large a quantity on the positive plate, and, being bulky, swells the coating and cracks it off.

The pasted plates, first introduced by M. Faure, are made with a conductor called a grid, so designed as to hold the pastes and make good electrical contact with the pastes.

Pasted Plates

The grids are usually made of hard lead—lead in which antimony is alloyed.

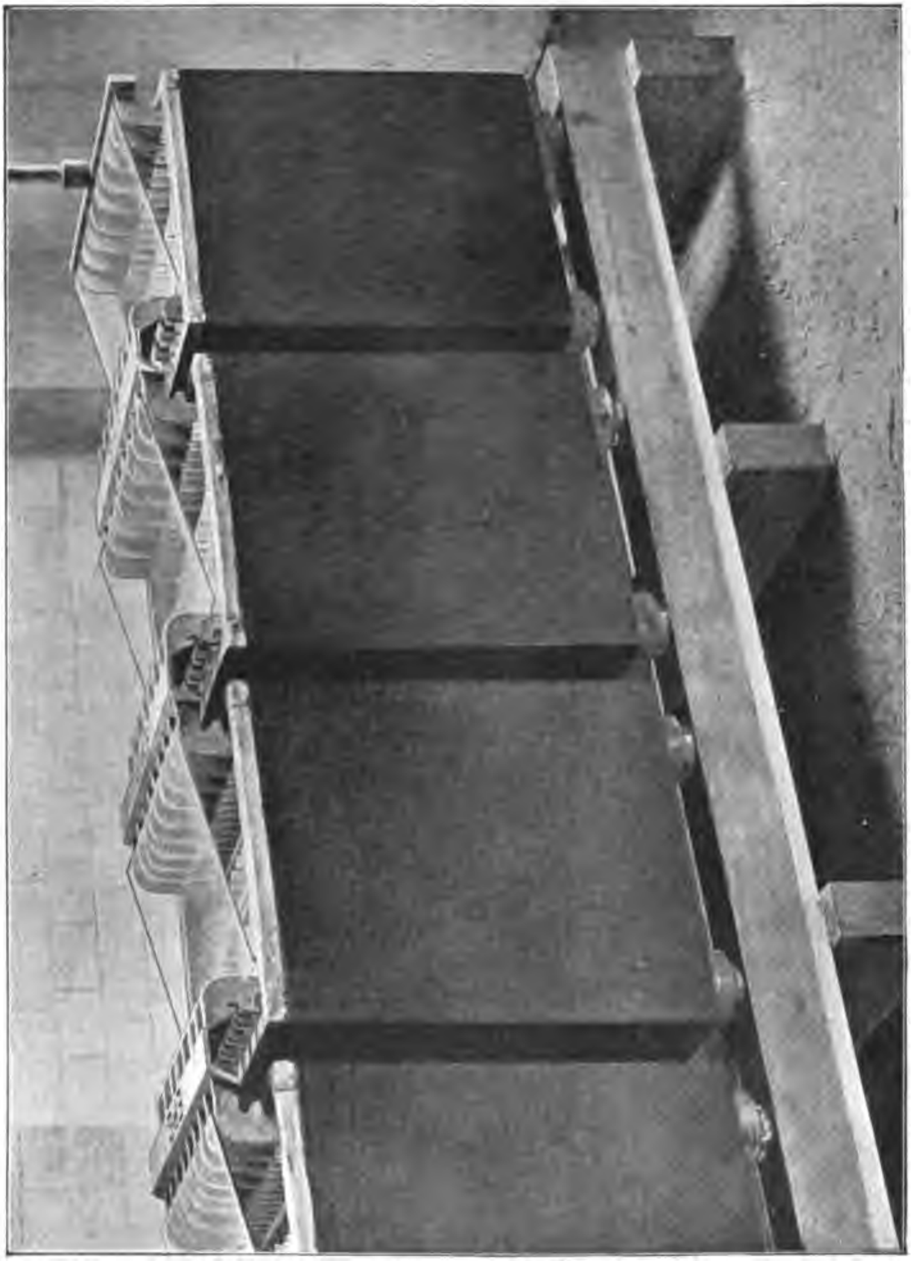


FIG. 1.—Tier of P. Type Cells, showing Method of Erection

The E. P. S. Coy. have from the beginning adhered to the pasted plates for both positives and negatives, and their cells have been very largely used for all purposes. They do not recommend

the same cell for all purposes, for their grids are designed to carry more or less paste for long or short charges and discharges.

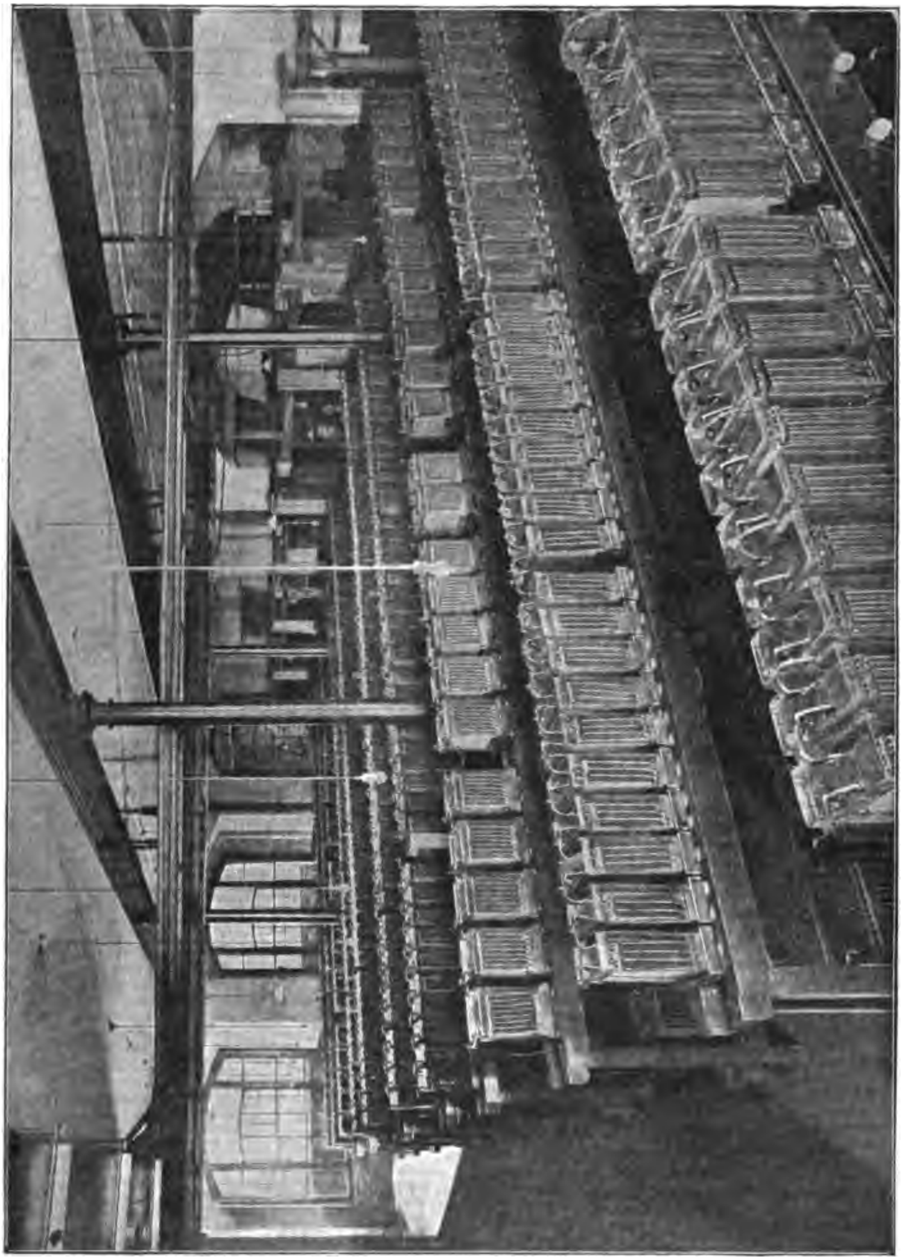


FIG. 2.—Battery of 700 K. Type Cells for Telegraphic Purposes at G.P.O., London
(These cells replace 30,000 Primary Batteries)

The following is a list of the various types of E. P. S. cells :—

P. Type Cells for Lighting and Tramway Work.—There are various cells of this type. Three P. 74 plate cells, having a capacity

of 1800 amperes for one hour, are shown in Fig. 1. The P. 17 double plate cell, having a capacity of 800 amperes for one hour, is specially designed for stations whose floor space has to be economised as much as possible.

O.K. Type.—For large power stations. This is a larger type than the above, and is also designed to economise floor space. The cell, O.K. 17, is capable of giving 900 amperes for one hour, or 430 amperes for four hours.

Cells in Glass Boxes.—Various cells of the Company's L., K., W.S., and W.T. type are mounted in glass boxes.

W.S. Type.—This is a lighter model of the P. type, and is serviceable for smaller central stations, isolated plants, &c.

K. Type.—Largely used in private house installations, and by British and Colonial post-offices for telegraph work. Fig. 2.

L. Type.—Useful for low discharges over long periods. This type is largely used in the smaller private house installations.

Cells in Wood Boxes.—Cells of the W.T. type are mounted in wood boxes, specially designed for ship lighting. Also some large K. and L. type sections.

Cells in Ebonite Boxes.—Faure-King cells are mounted in ebonite boxes. These are extensively used for motor car work; and E. type, which is largely used for electric launches.

The pasted cells are also made for traction work on motor-cars by E. P. S. Coy., the following table giving full particulars (42 amperes for three hours, 30 amperes for five hours, 25 amperes for eight hours):—

No. of Plates.	Max. Charge.	Discharge Amperes.			Approximate External Dimensions, including Ribs outside Boxes.				Approximate Weight.	Dilute Acid each Cell.	
		Rate for 3 Hours.	For 5 Hours.	For 8 Hours.	Length.	Width.	Height of Box.	Height over all.	Complete with Acid.	Weight of Acid.	Part of Carboy.
					Inches.	Inches.	Inches.	Inches.	Lbs.	Lbs.	
19	35	42	30	25	$6\frac{5}{8}$	$6\frac{3}{4}$	$10\frac{1}{4}$	11	43	$7\frac{1}{2}$	.065

To compare cells for traction work we divide the total ampere-hours capacity by the total weight of the cell. Thus, at five hours discharge, the efficiency would be $\frac{150}{43}$ = a little less than 3.5 ampere-hours per lb. of cell, or about 7 lbs. per watt hour. We shall have more to say on this point when other cells are considered.

At 25 amperes the output is $25 \times 8 = 200$ ampere-hours, or $\frac{200}{43}$ or 4.5 ampere-hours per lb.

Motor-cars usually carry 40 cells, in order to charge easily at 100 or 110 volts. This was all right in the past, when these pressures

were common ; but nowadays the charging of motor-cars must either be done by a separate engine and dynamo or by a motor generator, in which case the pressure can be made just what should be considered best. In the past, the motor-car man had to take what he could get in pressure; but now he must get what he wants, so that the chances of success are so much the greater.

The ampere-hours per lb. weight of cell increases largely as the cells increase in size, as a reference to the following table will prove. This table gives every detail information regarding E. P. S. traction cells in ebonite boxes.

Referring to the column of approximate weights per K.W. hour, it will be seen that the weight steadily decreases from 140 lbs. to 101 lbs. per K.W. hour. This clearly points to the use of large cells, lower pressure, and higher current values, for use in traction, and there is no objection whatever to large currents on board a car, as all the conductors are necessarily short. For instance, suppose we require 5 horse-power for five hours, and select a 9-plate cell giving 30 amperes, how many cells do we require, and what is the total weight compared with a 23-plate cell giving 83 amperes? Five horse-power is equal to $5 \times 746 = 3730$ watts, and $\frac{3730}{30}$, that is, watts divided by amperes, discharge rate, gives 124 volts as the necessary pressure. At 2 volts per cell we would require 62 cells at least, at 35 lbs. each, or 2176 lbs. total weight, very nearly one ton.

Now to get the number of 23-plate cells, $\frac{3730}{83} = 46$ volts required, or 23 cells at 86 lbs. weight = 1978 lbs.

The difference in favour of the large cell is $2176 - 1978 = 198$ lbs. A very considerable advantage, and worth considering.

No. of Plates.	Max. Charge.	Discharge Amperes.	Superficial Area.	Approximate External Dimensions.				Approximate Weight.		Dilute Acid each Cell.	
	Rate.	For 5 Hours.	Per Kilo Watt Hour Spread over 5 Hours' Discharge.	Length.	Width.	Height of Box.	Height over all.	Per Kilo Watt Hour Spread over 5 Hours' Discharge.	Complete with Acid.	Weight of Acid.	Part of Carboy.
			Sq. Ins.	Inches.	Inches.	Inches.	Inches.	Lbs.	Lbs.	Lbs.	
5	15	15	137	$2\frac{5}{8}$	8	12	13	140	21	$4\frac{1}{2}$	.038
7	23	23	121	$3\frac{1}{2}$	8	12	13	122	28	5	.044
9	30	30	115	$4\frac{3}{8}$	8	12	13	117	35	6	.052
11	38	38	108	$5\frac{1}{4}$	8	12	13	112	43	7	.060
15	53	53	104	7	8	12	13	108	57	9	.077
19	68	68	102	$8\frac{3}{4}$	8	12	13	104	71	11	.094
23	83	83	100	$10\frac{1}{2}$	8	14	15	101	86	13	.112

The pasted cell is best represented by those of E. P. S. Coy. The grids are cast to form a meshed plate of lead alloyed with

antimony, the meshes being designed for light weight and strength. Figs. 3 and 4 show two types of grids.

The grids must be chemically clean before applying the pastes. The pasting is an important part in the construction. A plate-glass topped table is best for the purpose. On this the clean grids are laid, and the paste prepared as follows: for negatives, pure litharge is used; it is important that it should be pure, finely-ground litharge of the finest quality, for any impurity will spoil the plates.

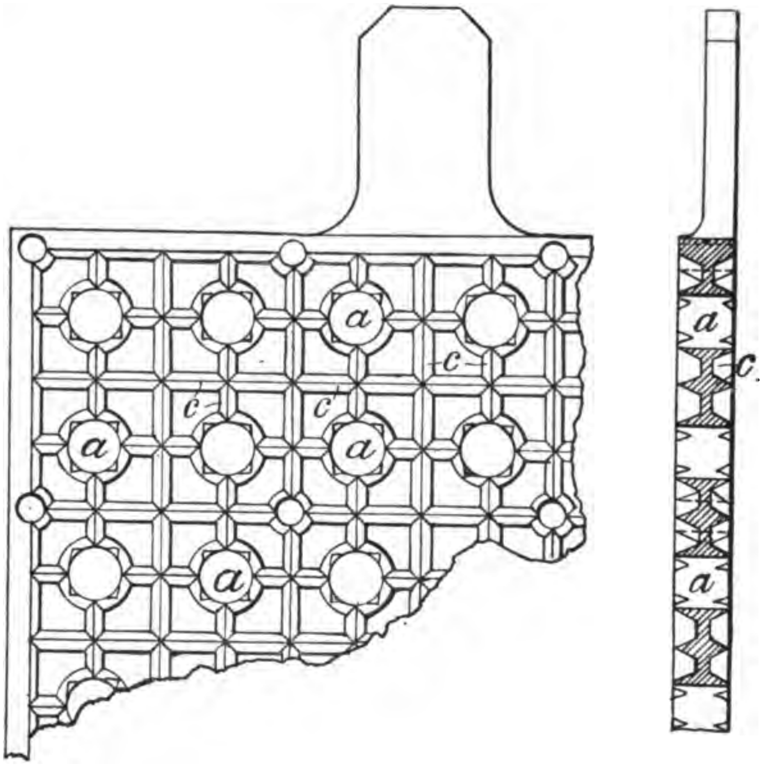


FIG. 3.—F. King's Grid for E. P. S. Batteries

The solution to form the paste must also be pure sulphuric acid in pure water. The specific gravity of the solution should be exactly 1200° Twaddle, cold.

Sufficient paste for two or three plates is made up at a time in a stone mortar. The litharge being weighed in, the acid is added to make an easily worked paste, well rubbed by a heavy pestle. As soon as possible the paste is plastered on to the grids, and well rubbed in and smoothed over by a trowel.

The paste soon sets hard, and the plates are laid away in an air draught, on racks, to thoroughly dry and harden.

The positive plates are pasted in the same way, with a paste

made up of pure red lead with a solution of pure sulphuric acid in pure water, specific gravity exactly 1100° cold. This paste does not stiffen so quickly, hence more of it may be made up at one time, and perhaps half-a-dozen plates filled from one mixing.

The plates are formed, after thorough drying, by assembling all the red or positive plates to form one set, and all the negatives or yellow plates to form the negative sets of the cells, into boxes, filled up with acid of 1170° strength. The current for forming must be very small at first, not more than one ampere per 35 square inches of positive plates, and the forming must proceed at this low rate for 120 hours, and then the current may be increased to double that for some time, say ten hours, and then for five or six hours at the full charge rate required. The cells should then be discharged down till they indicate 1.8 volts each, on a discharge rate not more than ¾ths that of the normal discharge rate; they should then be charged again at a rate of about ¾ths the normal charging rate, until at least double the ampere hours of their capacity has been run into them. They will then be ready for use, and must be carefully kept charged, and never discharged at any time below 1.8 volts.

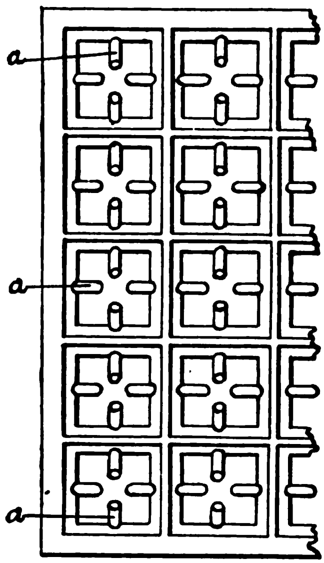


FIG. 4.—F. King's Grid

The E. P. S. cells are partially formed when delivered, so that the following instructions for first charging are given:—

1. Charging must be commenced immediately after the solution is added, and should be as continuous as possible for the first charge. On no account should the dynamo be stopped for the first twelve hours, nor should the battery be used to supply current till the acid in every cell has turned milky in consequence of the vigorous evolution of the gases from both positive and negative plates, nor until the specific gravity has risen at least to 1195.

Should one set of plates commence to evolve gas before the other, the charging current should be reduced to about half rate.

It may be mentioned that the specific gravity of the acid will fall when it is first put in the cells, and may not commence to rise for a considerable time after the charging has started.

The total duration of first charge at normal rate may be as much as thirty to forty hours, and the above directions should be strictly adhered to.

2. The rate of charge may be ascertained by reference to the

list; the most economical rate being that represented by the lower figure in each respective case.

3. The battery should always be kept as fully charged as possible, in order to avoid the risk of complete discharge.

It should be remembered that completely discharging a battery has the effect of shortening its useful life. If there is not time during the available working hours to fully charge the cells, the dynamo and engine power must be increascd, or the draught from the battery reduced.

The battery should be charged to a sufficient extent to cause the liquid to become milky at least once a week.

4. Before the battery is switched into the charging circuit, care should be taken that the field magnets of the dynamo are properly excited, and that the proper E.M.F. is being generated.

5. The battery must be switched out of circuit before the dynamo is stopped.

6. The normal maximum rate of discharge should not be exceeded. When the battery is capable of supporting only a part of the total load, an automatic alarm should be placed in the battery discharge circuit.

7. Loss of liquid will be greatly retarded by the use of glass or other non-conducting plates laid in the acid at the top of the plates, as the gases are collected thereby and spraying is prevented.

8. The plates must be kept covered with liquid, any loss of which must, when necessary, be made up only by the addition of pure water; acid should not be added except under the advice of the Company.

9. The condition of each cell should be tested at least once a week by means of the cell tester or volt meter. This test should be made while discharging at the normal maximum current.

10. The specific gravity of the acid when the cell is fully charged should be from 1.200 to 1.210, and the discharge should never be continued after the specific gravity has fallen to 1.170.

11. Any cell in which the liquid does not turn milky with the remainder should be carefully examined. Contacts caused by pieces of paste, scale, &c., should be immediately removed. and the cell cut out of circuit during the discharge by disconnecting one terminal of the cell and connecting the two adjoining cells by means of a piece of cable large enough to carry the discharging current. The cell should be restored to its position in the circuit when charging, and it will be generally found that one or two charges restore the cell to its proper condition.

12. Arrangements should be made on the switch-board to enable the number of cells, in both charging and discharging circuits, to be varied at will, and facilities should always be provided so that the

current in either circuit can be measured. (See Fig. 161, page 133, Vol. II.)

13. The connections throughout the battery must, if they are not soldered or burnt together, be kept perfectly clean; brass or copper in proximity to the battery may be protected with vaseline or paraffin oil.

14. If it is required to leave the cells out of work for any length of time, the acid must not be removed, but the battery must previously be fully charged, and care taken that the plates are well covered with liquid. If practicable, a short charging should be given, say once a fortnight, till the acid turns milky, by which treatment the cells will be kept in order for any reasonable length of time.

The best example of the purely Planté type of cell is the Epstein cell as made by Messrs. O. Rooper. The plates are foliated on the surface, and are of pure lead. The surface is rendered spongy, or porous, by repeated dipping into a hot 1 per cent. solution of nitric acid and water. In this way a crust of spongy lead is formed. The plates are then assembled into cells, and "formed" by long continued charging and discharging.

Epstein thoroughly investigated this form of cell, and made it the most successful of its kind. And recently I had three cells under severe tests, which they came through with better results than any others; they were of Messrs. Rooper's manufacture, and were submitted to repeated charges cold and discharges hot, a test which no pasted cell can stand for long, but these plates showed no signs of breakdown while the tests lasted.

The effect of heating the electrolyte during discharge is to largely increase the capacity; in fact, the cell gives out more energy than is put in at the charge, the heat in some way being converted into electrical energy. The effect however diminishes, and the cells become of less and less capacity. Heat affects all batteries by raising their pressure and increasing the output of energy.

My own experiments on the effect of heating the cells were anticipated by C. Heim, in a paper describing results which are quite the same as my own—a paper read before the electrical society in Dresden, 29th June 1901. From an abstract in the *Electrician*, of London, the results below are given:—

The first experiments were made with a Hagen Accumulator Co.'s cell for heavy discharges, type E 53, capacity 69 ampere-hours, at a three-hour rate, with three positive and four negative plates 180 mm. x 170 mm. The superficial area of the positive plates is 18.9 sq. dcm. The acid strength after discharge was from 1.21 to 1.22 at 18°. This element had been previously charged and discharged 160 times. It was tested at 14°, 30° and 45°C.; forty-six

discharges in all were made at these temperatures. Prior to the experiments eighteen charges and discharges were made to bring the cell into good condition. Subsequent experiments were made with five larger cells of the Hagen Co.'s type E 21, of 432 ampere-hours capacity at a three-hour rate. The acid strength after discharge was 1160 at 15°. The temperatures employed were 12° and 45° Cent., and the total number of discharges was 11. Only two preliminary charges were given in this case as the cells had been in regular use in the laboratory.

Heating was effected in the case of the smaller cell by hot water circulating through a leaden worm arranged in a flat spiral underneath

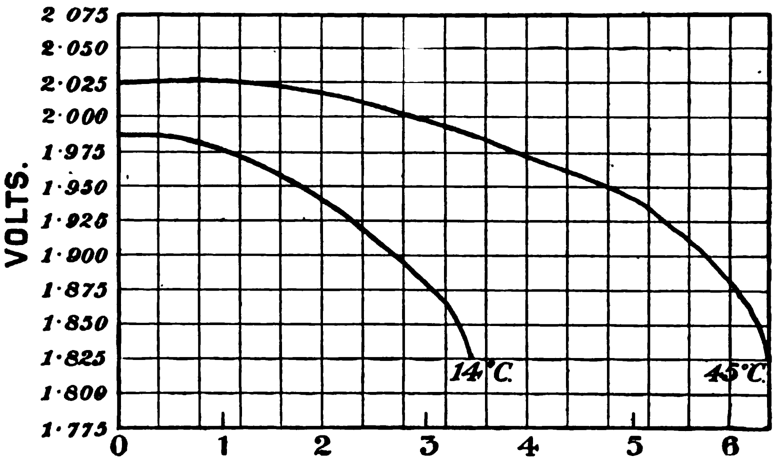


FIG. 5.—Experiment with 20 Amperes Discharge Current

the cell, the space between worm and lower edge of cell being 40 mm. For cooling, a flat worm was arranged immediately over the plates. The cells tested were surrounded by a felt jacketing to retain the heat. During the tests the temperature was found to vary by 5° between top and bottom of cell, and in the readings always a middle point was taken. The warming of the larger cells, which were in lead-lined wooden boxes, was effected by gas burners arranged below them. To cool them it was found sufficient to leave the window open near them. The loss by evaporation was compensated for by the addition of warm water before charging. 1.80 volts was adopted as the point in the fall of E.M.F. at which the discharge was regularly interrupted.

The smaller cell was discharged at 20 amperes and 32 amperes throughout the tests, corresponding to current densities of 1.06 amperes and 1.69 per square decimetre respectively. With the large cells the current was 140 amperes = 1.37 amperes per square decimetre. All the results from which the data have been taken

were obtained from discharges following immediately on charge, though in the case of the larger cells a night usually intervened between charge and discharge.

Experiments with the single-cell type E 53 showed that with a discharge current of 20 amperes the capacity rose from 71 ampere-hours at 14° to 128 ampere-hours at 45°; while, with a current of 32 amperes the rise was from 53 ampere-hours at 14° to 82 ampere-hours at 30°, and 112 ampere-hours at 45°. This is equivalent to an increase of capacity of 3 per cent. for each degree above 14°. Experiments with the five cells of type E 21, with a discharge current of 140 amperes, showed a rise of from 386 at 11.3° to 735

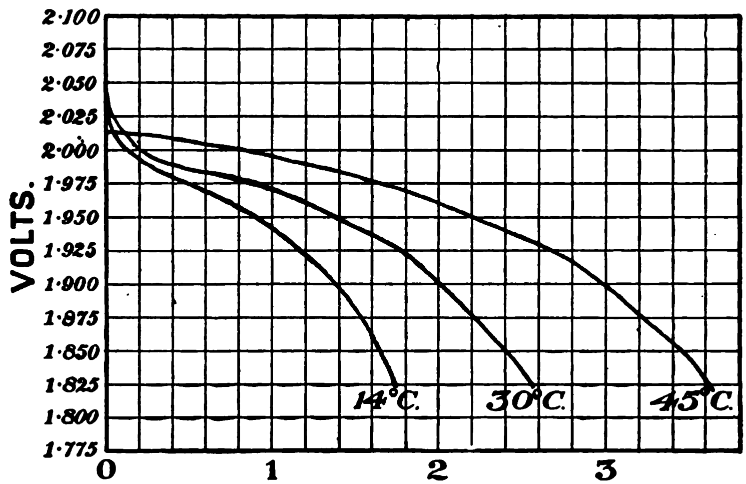


FIG. 6.—Experiment with 32 Amperes Discharge Current

ampere-hours at 45°. This is equivalent to a rise of 2.7 per cent. per degree between 11° and 45°.

Owing to the slight increase in voltage at the higher temperature, the discharge at 20 amperes at 45° (in the case of the small cell) down to 1.80 volts as indicated, is really equivalent to discharging down to 1.786 volts. If in Figs. 5 and 6 we carry the comparison curve at the lower temperature on to this point, we find the increased capacity at 20 amperes to be greater by 2 per cent., and at 30 amperes by 3 per cent.

A number of estimations showed that during discharge at a high temperature the acid density diminished in a greater degree than in the case of a discharge at lower temperature.

It was to be expected that, owing to the increase in capacity through heating, if charging was conducted at a low temperature and discharging at a high temperature, a greater number of ampere-hours would be got out of the cell than was put in. Both this and

its converse were proved repeatedly to be the case. Thus, discharging at 32 amperes at 45° 96 ampere-hours were obtained, while only 61.9 ampere-hours had been put in at the same rate of charge at 14°. Conversely, charging in 128 ampere-hours at 45° only yielded 65.6 ampere-hours on discharging at 14°. Further, a cell that had been discharged at 14° was heated up to 45° and another 17.6 ampere-hours got out of it. To prove that this was not due to recuperation on standing, the same cell was left standing for 1½ hours at 14° after being discharged. On then further discharging it at the same temperature only 4.3 ampere-hours more were obtained.

As regards efficiency, this is apparently less in the case of charging and discharging at the higher temperature, the mean value

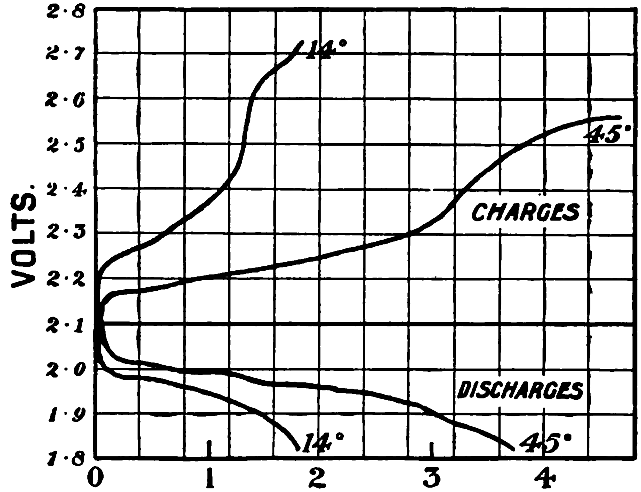


FIG. 7.—Comparison of Efficiency

being at the temperature of 14° (in the case of the small cell) 95 per cent. At 45° it was only 86 per cent. Part of this difference, however, is only apparent, as the counter E.M.F. (as shown in Fig. 7) does not rise as much on charge, and the *energy* put in is therefore proportionately less.

The result of these experiments is to show that the influence of temperature upon capacity is considerable. It is also probable that it increases with the current density.

Practical applications of the principle depend on the assumption that rise in temperature does not injure the plates. The laboratory experiments have not given ground for a definite conclusion in this respect; 25 discharges, mostly at 45°, did not appear to have done any injury. The Hagen Company, however, are of opinion that warming the cells causes premature destruction. They conclude this from the observation of station batteries mounted in very warm situations and from laboratory experiments. Assuming, as appears

probable, however, that the depreciation is not serious, practical results follow. The capacity of stationary batteries may be temporarily increased, say, in winter. If the regular heating is ultimately found destructive the plan may, at any rate, be adopted occasionally. Batteries may also be heated at such times as they are likely to be most subjected to heavy discharges. For electromobiles, also, the principle might apparently be employed with advantage, more especially as the rise of temperature of cells on a car is usually not more than 7° above that of the atmosphere, even at high discharge rates and with the cells packed closely together. In the case of tramways, however, not much can be looked for, as the heating is at present quite excessive, owing to the heavy currents almost regularly taken out of the cells.

The phenomena have their counterpart in the fact that the capacity of batteries is considerably diminished in cold and frosty winter weather.

Whatever may be the exact amount of the increase in capacity in any given cell when its temperature is raised, the facts here brought forward will at any rate necessitate that temperature shall in future be taken into consideration in all questions affecting the capacity of lead accumulators.

The Epstein plates are made up into cells for all purposes and capacities; both for stationary and portable purposes they may be considered as the typical Planté form of modern plates, while the E. P. S. may be similarly considered as the type of purely pasted plates.

Another type of cell largely employed has a pasted negative and a Planté positive plate, and it is claimed for the combination that it gives greater capacity and greater durability than either of the former types. This claim is based on the facts that a pasted negative has a higher capacity than a Planté negative of same weight and size, and that a Planté positive is more durable than a pasted positive plate of same capacity. My own experiments on this point confirm this theory. They were made with various positive Planté plates and a negative pasted plate made for the purpose of tests. Epstein positives supplied by Rooper gave on the whole most satisfactory results.

The negatives were made as follows: of thin perforated sheet lead in three leaves, the leaves were burnt together at one end to form a solid connection to a connecting lug; a uniform layer of paste $\frac{1}{16}$ inch thick was laid between the two outer leaves and the central one, and one of the outer leaves being broader and longer than the other two was folded over to form a closed envelope all round the three edges. This formed a most durable negative of high capacity, the paste becoming a hard porous plate of active negative material, and

cells so made gave as high as 13 watt-hours per lb. of complete cell.

Many cells are now made of the two kinds of plates, the aim being to get a large quantity of active negative material in a fine porous condition in contact with the grid, and a large surface of sheet lead peroxidised on the positive plates.

The chloride cell is one of this type, also the Monobloc and Tudor cell.

In stationary cells weight is not of much consequence further than it increases cost, but in traction and other portable cells it is of prime importance. Stationary cells are made heavy to give a maximum of endurance, and they can, generally speaking, be pretty carefully looked after in use, so that they are treated with all the care that experience has taught to be necessary to keep them in good healthy condition. Never overworked, never run down below a fixed voltage, the maximum discharge rate never exceeded, regularly, well, and fully charged—under these conditions their life is long and maintenance cheap.

But these are exactly the conditions difficult to comply with in traction and portable work. For the load varies very largely from moment to moment and is unknown nearly all the time, and to save weight the cell is always made as small as possible; they are consequently overworked often, but the chief cause of failure is the unknown amount of discharge going on. It is difficult to tell their condition, a motor-car with accumulators is like an overdriven horse on a bad road, the work must be done anyhow, and so the accumulator is put to it, but at the expense of its constitution. It may be said that the voltmeter would show the cell's condition; quite true, but on a journey we cannot stop anywhere to charge an accumulator, we must go on to the journey's end at any risk. Road traction is very variable in the amount of power required, hence an accumulator which may easily do fifty miles on one charge one day may be quite exhausted on thirty miles run next day. It is this uncertainty of the power taken by a road car which causes the failure of motor-cars driven by accumulators. Hitherto electric traction by accumulators may be admitted to be a dismal failure, whether on road cars or street railways, for, added to the above difficulties in dealing with them fairly, there are the mechanical difficulties, vibration and jolting, which breaks up the plates and their connections, and finally, their great weight per horse-power hour. The accumulator has still to be made to solve the electric traction problem. Another fallacy regarding the use of accumulators is worth exposing, and that is the notion that they can be employed as regulators. At a very early date it was proposed to put in accumulators across the mains of supply systems, in order that when a large

load came on and caused a drop in pressure in the mains, the battery would feed into the mains and make up for the loss, and then when the load was light the pressure on the mains would rise above that of the battery, and therefore feed into the battery, recharging it again ; a very pretty theory but impracticable.

In the first place, the rise and fall of pressure in the mains due to the load is very variable, the fall lasting only for a short period in 24 hours and the rise for a long period. Secondly, the rise and fall in the mains causes a rise and fall of pressure in the battery itself. If the mains could be kept at constant pressure the battery would not be necessary. The battery acts only if there is a rise or fall of pressure, the very thing it is supposed to prevent. In this it is like the governor of an engine, the engine must run faster or slower before the governor acts, and no governor nor regulator can maintain a constant speed or pressure.

A battery may help by feeding in current during the time of great demand, using hand regulation.

Then we have the same uncertainty as to the charging and discharging going on. Accumulators may be admitted as failures when used as automatic regulators alone, but when used with a special booster, as we shall presently see, they become very successful regulators, especially for traction circuits.

Proposals to use accumulators in traction vehicles, carrying an engine and dynamo to keep them charged, have been seriously made, and cars actually built and run carrying a whole electrical engineering arsenal—engine, dynamo, accumulators, and two motors. Such wild-cat schemes crop up continually ; they are usually made by men who make up schemes which they call inventions, in subjects and for objects about which they quite readily assure one they don't know the science or art of, but, being inventors and men of genius, they can conceive improvements which the expert of long experience never dreamt of ; and such absurd proposals often receive support where genuine improvements are condemned to neglect.

The electric accumulator has a very great field of usefulness, when applied by intelligence and skill, and although far from perfect, it has become almost indispensable, and fairly large manufacturing interests have grown up in their production.

The maintenance of stationary batteries well treated is as low as 7½ per cent. in some cases, and seldom over 10 per cent. (not including attendance, which is necessary). A battery of any considerable size requires a skilled attendant responsible for its condition and treatment just as much as an engine and dynamo do.

The efficiency is low from two causes. First, the charging pressure averages about 2.4 volts, while the discharging pressure averages 2 volts per cell. Second, the ampere-hours given out are only about

90 per cent. of the ampere-hours put in, so that, if we put in 100 ampere-hours at 2.4 volts we have expended 240 watt-hours, while we get out $90 \times 2 = 180$ watt-hours $= \frac{180}{240} = 75$ per cent. efficiency approximately.

Having now considered the subject generally, the construction of some later cells is of interest, not from any new principles embodied in them, but from improved details of construction. The lead accumulator seems impossible of further development, and no other element has yet been found equal to lead for plates.

The E. P. S. cell is too well known to require much further description; we may only refer to the grids. As it is a pasted cell the grids are of great importance. They must be designed to withstand the acid solution and the electrolytic action; they form the skeleton of the plates, and, as far as possible, should be covered by the active materials, and so protect them; the grid must also ramify the active material and prevent it from breaking away. Fig. 3 represents part of a grid designed by Mr. King of E. P. S. Company, and Fig. 4. another simpler design; both are very good for stationary batteries. Fig. 8 represents three sections of plates; in Sects. 1 and 2 the black parts are the lead grid, the shaded parts the paste, in 3 the black part the grid infoliated forming little shelves to carry the paste.

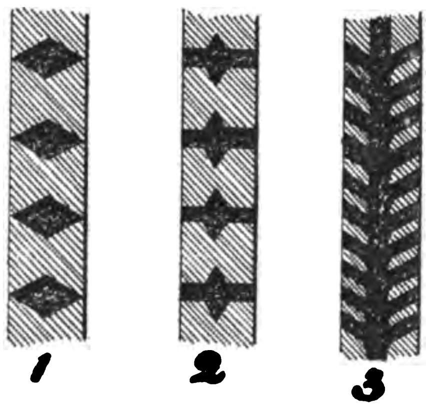


FIG. 8.—Sections of Grids

For motor-car and tramway work cells of small weight are desirable, and many efforts have been made to reduce the weight.

Theoretically, we should get about twenty-five watt-hours per lb. of cell; practically, in ordinary cells, we get only six or seven watt-hours per lb., and no special cell has given better than thirteen watt-hours per lb.

After a long investigation with cells constructed specially for traction, the author came to the conclusion that cells could be made to give fourteen watt-hours per lb. at a fair discharge rate, but that their life was very short, and therefore their cost in running high. A cell giving about nine watt-hours per lb. seems to be about the best that can be obtained with economy in any known accumulator.

Lead is a very heavy and weak material, and a poor conductor, hence it must be used in considerable bulk to meet the mechanical and electrical requirements.

A plate made by Gulcher has glass rods interwoven in it to give it strength. Fig. 9 shows a piece of this plate which consists of a woven fabric having warp threads *a* or lead wire and weft threads *b* of glass or quartz threads. The ends of the lead wires are left exposed for some distance from the main fabric, and a frame of molten lead is cast around it whose upper bar *c* has lugs *d* for suspension and a conducting tang *e*.

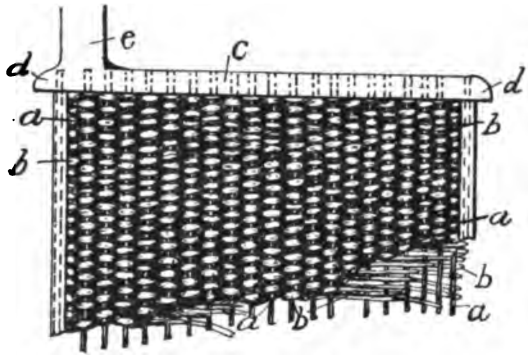


FIG. 9.—Gulcher's Woven Plate

The plate is then plastered with active material in the same way as a grid plate. Each plate *f*, Fig. 10, is wrapped in a layer of glass cloth *h*, and pressed in groups between two insulating stands *i* connected at the top by comb-shaped plates *k* between whose teeth the lugs *d* rest. The two stands *i* are also connected together below by bars *n*. The tangs *e* are connected to a common conducting strip *g*. The glass gives the plate an indestructible backing, hard and resilient, so that a light plate is formed of great capacity at moderate rates of discharge. At high rates of discharge it is not a success, for the amount of lead in the plate is not sufficient for carrying large currents.

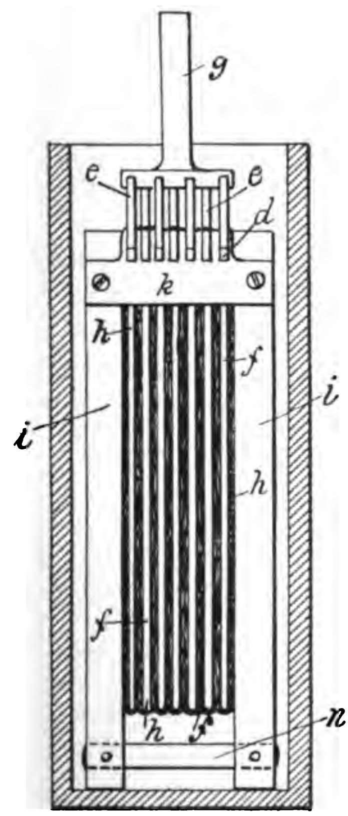


FIG. 10

At the present moment the only cell fit for reliable work on motor-cars is one with an Epstein positive and the perforated lead enveloped negative as referred to already, this combination coming out a long way ahead of all others in a long series of tests on cars and in the test room.

Motor-car people are apt to pin their faith to road racing or running tests, and to condemn scientific tests; that is but natural among individuals who are more sportsmen than scientists, hence the many failures of electric motor-cars. The battery experts could have told them how they would fail without any trials on road-running cars.

Before any battery is tried on a car it should be thoroughly tested by a competent expert, not necessarily in school, college, or training institution laboratory, but by a practical engineer who knows the important points, and wastes no time over others, no doubt of scientific interest, but of no importance in practice.

A successful case of battery traction arises in shunting operations on railways. Here the locomotive has to be ready all the time for short runs, so that a steam locomotive is expensive to keep up always under steam, and with two men idle for hours and then engaged for a short time.

Fig. 11 illustrates an electric locomotive connected with the

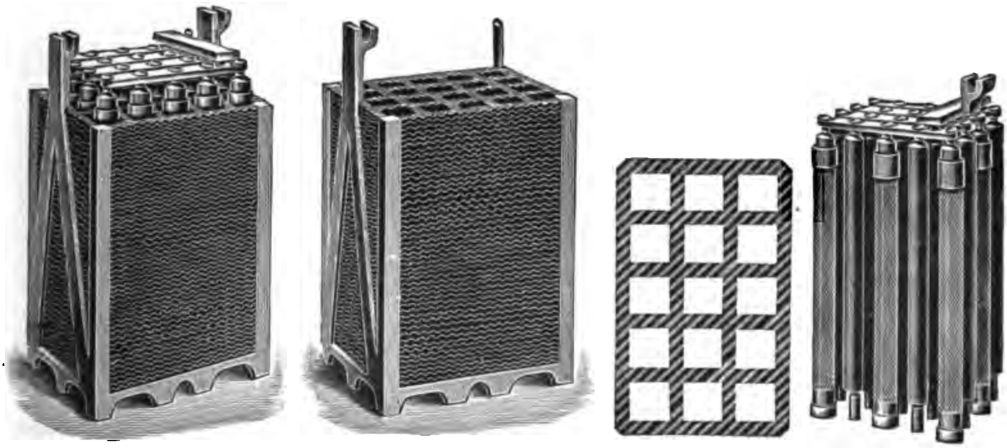
FIG. 11.—Electric Locomotive

Lancashire and Yorkshire Railway. The locomotive is equipped with sixty No. 25 Monobloc accumulators, illustrations of which are also shown in Fig. 12. These cells have a capacity of 525 ampere-hours, and are capable of charging or discharging at 105 amperes for five hours, 125 amperes for three and a half hours, or 390 amperes for one hour. It is claimed for these cells that vibration does not dislodge the active material, and that there is no buckling or breaking of the plates.

As will be seen, the block of the positive material is composed of punched sheets of lead, built up from the bottom of the cell, so as to form one homogeneous mass, which is cross-tied at all points to give the maximum mechanical strength. The holes punched in

these horizontal sheets also form a casing and receptacle for the negative electrodes, which are in the form of vertical pencils. The positive block is formed by a special variation of the Planté process, which insures a dense and closely adherent coating, which has been shown in actual practice on a large scale to resist the disintegrating effects of rapid discharges. Free circulation for the acid is provided at all points throughout the cell, and the novel arrangement also insures the even distribution of the electric current throughout the mass, which is essential in every well-designed accumulator.

The locomotive, which is capable of drawing 120 tons, is mounted on two axles, with four wheels 43 inches in diameter. Each axle is geared to an enclosed traction motor, geared to the axle by double-



Complete Cell — Positive Block — View showing Corrugated Lead Sheet with holes for Negative Rods — Negative Rods

FIG. 12.—The Monobloc Accumulator

reduction, machine-cut, spur gear, having a ratio of 20 to 1. Each motor gives a horizontal effort at the tread of the wheels of 2500 lbs. The motors also give 1000 lbs. horizontal effort at from three to four miles per hour, with 68 amperes and 120 volts. They are specially designed to operate in conjunction with storage batteries. The controller is of the series-parallel type, effecting these combinations on the motors, and not by manipulation of the battery. The locomotive is complete with instruments for registering charge and discharge of the battery, and controlling the locomotive from either end for shunting operations. The total weight, in running order, is 22 tons. At the trials which were recently conducted the result was satisfactory, the locomotive starting with ease under the maximum load required, and being under perfect control. In shunting operations in connection with goods yards there is a considerable field for the electric locomotive, for not only is the

risk of fire among timber and other inflammable goods avoided, but actual economy should result from the fact that the ordinary locomotive has to be kept under steam for many hours in order to be available for comparatively short periods of use. Apart from this, the labour required for the manipulation of an electric locomotive is less than that which has to be provided for its rival, the steam locomotive.

This Monobloc cell is of good design. Many cells exist on somewhat similar lines, exposing a large surface of thin material well bound together.

The Chloride battery is also a composite one, with Planté positives. It is made as described below.

The first step in the manufacture of the Chloride cells is the making of chloride of lead. Litharge, which is the basis of the product, is dissolved in large vessels, which rotate round mechanical stirrers. The litharge is dissolved by means of acetic acid, which gives the resultant compound of acetate of lead. After the lead acetate has been drawn off and allowed to settle, it is then precipitated by means of hydrochloric acid, which practically gives us chloride of lead. The process is not quite so simple as described, as when the compound reaches the acetate of lead stage it has to be carefully analysed, and also when it arrives at the chloride of lead stage. The cakes are dried in large ovens.

The chloride of lead next makes its appearance in what is known as the pastille casting department. In this room the chloride of lead is melted in large gas-heated iron pans. The pans are protected by means of refractory linings, and a layer of lead some inches in thickness protects the bottom. The chloride is put into the pans with a small percentage of zinc, and becomes perfectly fluid at about 600° Cent. It is ladled out by means of plumbago ladles, and cast in moulds into small hexagon pastilles suitable for framing. The pastilles are then carried away to be framed. The pastilles are arranged in the bottom half of a plate mould, the top half of the mould being permanently fixed to the top side of a hydraulic press. After the pastilles have been arranged on the mould it is placed in position on the ram by means of stops, and water being admitted to the ram chamber the press is closed, and the top half of the mould comes down on to the bottom half. The next operation is to inject molten lead under pressure to fill in the interstices left in the mould. This is done through a nozzle, which, by means of a screw, connects the molten lead chamber to the mouth of the mould. Compressed air is then admitted into the top of the lead chamber, with the result that lead is forced into the mould, completely filling it and bedding in the pastilles.

The lead chambers are placed around a large pan of molten

lead, four chambers and presses being arranged round each lead pan. The compressed air is delivered into the lead chambers at a pressure of 150 lbs. per square inch. The operation of the lead press is safeguarded to prevent pressure being applied to the lead chamber until the press has been completely closed.

The next process is to trim the plates, and after this they are taken to the reduction tanks, where they are set up alternately with rolled zinc plates, with the result that the chlorine in the chloride of lead pastilles leaves the pastille uniting with the zinc and forming chloride of zinc in the tank, the final state being that each pastille is converted into one of pure spongy lead. After a process of washing, the plates are then given a hydrogen bath to insure absolute freedom from all trace of chlorine. That operation practically completes the making of the negative plate. They are then passed on to the plumbers, who cast them into sections ready for sending out, putting the plates in a specially shaped mould in which molten metal is poured.

The manufacture of the positive plate is a simple operation. The positive grids are made first. They are cast in moulds by means of compressed air, as in the case of the negative plates. The material is antimonial lead, and the moulds are arranged to leave a series of holes in the frames, and into these holes are pressed cores of lead in the form of a pure lead spiral, and the process of making this coil or spiral is interesting.

The lead is first formed by means of a hydraulic press into ribbon about a quarter of an inch wide, which is wound on drums. This ribbon is then passed through specially designed machines, which rib and cut it up into short lengths, which are then automatically rolled up into coils.

The coils are then pressed by hand into position in the plates. When the plates are filled they are passed through a hydraulic press, which completes the keying of the coil mechanically, the plate being then practically ready for "forming." The formation is effected by coupling up the plates with a set of dummy negatives, and passing the current continuously through the cells, the lead coils becoming finally coated with a fine adherent hard crystalline coating of peroxide.

After the formation process, the plates are cast into sets, in a similar manner to the negative.

Fig. 13 gives a good idea of the appearance of the cell in its completed form, and Figs. 14 and 15 show respectively the construction of the positive and negative plates.

It will be seen from this description that the Chloride cell in the finished state has no chloride about it. The chloride is used to form the spongy lead in the negative plate only. In other cells this

spongy lead is formed from litharge direct in the forming process by long continued charging at a low rate.

The Chloride Battery people have introduced a special booster for regulating battery circuits in conjunction with dynamo circuits. We have already seen that batteries used alone as regulators are not a success; but so used with a booster, as introduced by Mr. Highfield, described as follows, they are a great success, especially on tramway circuits and railway circuits.

This booster is of a special design for working in series with a storage battery, and effectually does away with the inconvenience and expense of regulating cells and hand regulating switches. It also

CHLORIDE CELL

FIG. 13.—Complete Cell

FIG. 14.—Positive Plate

FIG. 15.—Negative Plate

does the work in a manner quite unattainable by any other method, and keeps such a fluctuating load as a tramway one with a practically constant potential, and also the load on the generator the same throughout. This result is obtained in the following manner. The booster armature is always in series with the battery. The machine is run throughout the time the generators are working, and sometimes when the battery alone is working the line.

The essential connections are shown diagrammatically in Fig. 16, and the machine itself in Fig. 17. This shows the booster driven by a motor; it might, however, be driven from the main engine.

The booster B. (Figs. 16 and 17) has laminated field magnets excited by a fine wire coil C (the exciter coil), consisting of such a number of turns of such resistance that the pressure given by the

armature when run at constant speed is the same as the pressure across the ends of the exciter coil. The exciter E is a small generator, giving the voltage used on line and the necessary exciting current. This generator has a very small drop for no load to full

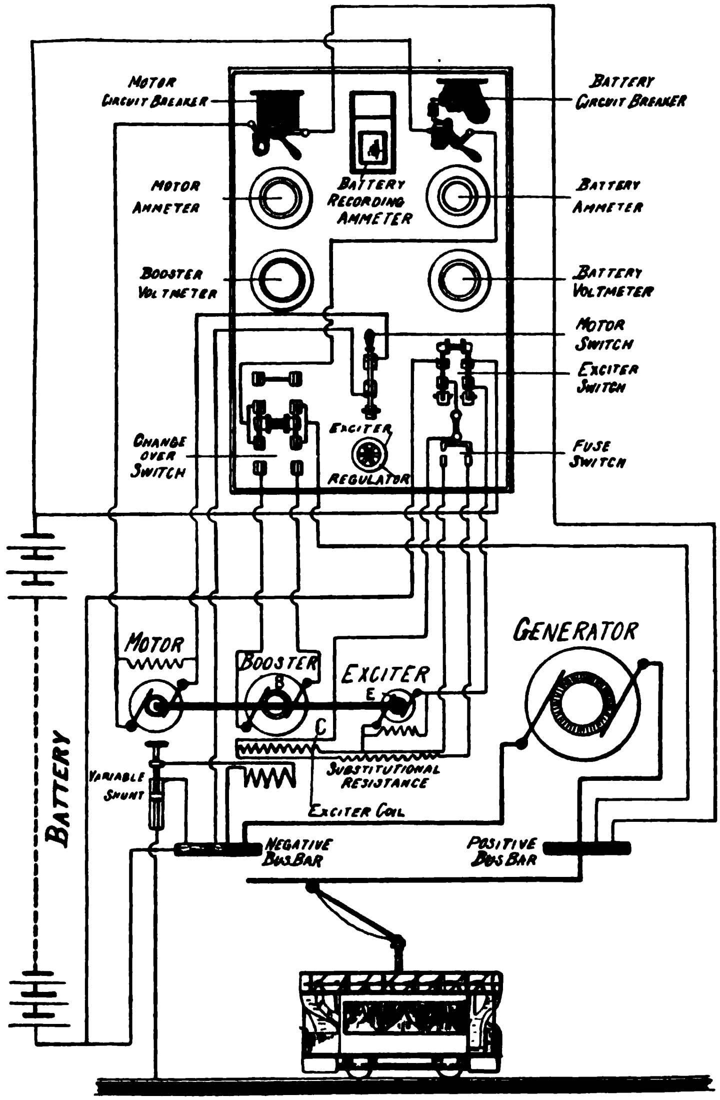


Fig. 16

load, which drop is corrected by a series winding; its armature leads are coupled on to the battery negative terminal by way of the exciter coil C. So long as the exciter and battery pressures are equal, no current will flow in the exciter coil, and hence the booster will give no pressure; but, should the battery volts rise, a current will move in

C proportional to the difference of the pressure of the battery and of the exciter (which will be motored). The booster armature will then give a pressure equal to the rise of the battery pressure. Similarly, should the battery pressure fall, the booster will give a pressure equal to the fall, but will have its poles reversed, the exciter running as a generator and giving current to the battery. The booster therefore follows the variations of the battery pressure from the line pressure, and corrects for the variations, so as to maintain the line pressure constant whether the battery be charging or discharging. Generally, as will be readily seen, the exciter runs as a motor when charging and as a generator when discharging; but since only 240 cells are used occasionally when the cells are low, charge begins at a less pressure than the 520 volts on the line, the booster then runs

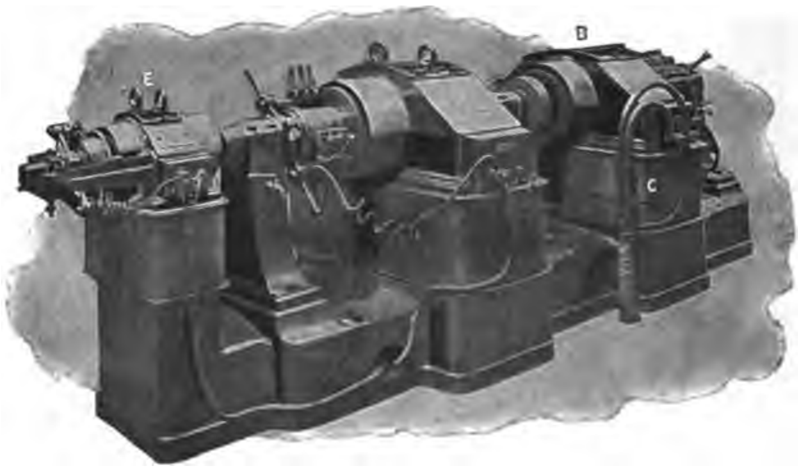


FIG. 17.—Highfield Booster

as a motor, and the motor as a generator, returning energy to the line; also, when the battery is fully charged, the pressure is generally greater than the line pressure. Should the battery in this condition be called on to discharge, the booster opposes the discharge and is motored; the motor then runs as a generator and again returns energy to the line. The current variations in the motor amount to about 7 per cent. of the maximum line variation. The booster fields being laminated, and being designed to work at a low induction so that the field strength is as nearly as possible proportional to the magnetising force, the change of polarity is rapidly made, and the booster pressure varies very closely as the difference between the battery and exciter pressures. Such a booster, connected in series with the battery, will serve to maintain nearly constant the load on the generator, as it will nearly correct for all charges in the battery pressure.

There will be times, however, when the current through the booster armature is large and the field very small; the armature reaction will then be an important factor in the working of such a machine. To overcome this a coil, connected in series with the armature, is used, so that it opposes the reaction of the armature in whichever direction the current flows; this coil consists of a few turns only. In order to increase the pressure as the load on the line increases, a part of the feeder current is shunted round a coil on the booster fields in such a direction as to help the discharge or to oppose the charge, or a part of the feeder current may be taken round the exciter fields so as to raise the exciter pressure, or a part of the feeder may be taken round the motor fields so that, the greater the load becomes, the greater is the motor speed, and hence also the exciter and booster pressure in the discharging direction.

In attending upon cells, matters are much simplified if an ampere hour recorder is used, with a good clock and an open scale; also a battery watt-hour meter, showing the state of the cells during charging and discharging. These points have already been referred to in Vol. II.

It is also necessary to take the sp.g. of the solution in the cells at intervals. For that purpose any hydrometer scale may be used, Beaume or Twaddle.

Deg.	Sp. Gr.
11	1083
12	1091
13	1100
14	1108
15	1116
16	1125
17	1134
18	1143
19	1152
20	1161
21	1171
22	1180
23	1190
24	1199
25	1210
26	1221
27	1231
28	1242
29	1253

The two scales are here given within the range of battery work. The first column is Beaume degrees, the second Twaddle scale.

A special instrument, useful for batteries wherein ordinary hydrometers cannot be inserted, is here illustrated (Fig. 18) as supplied by E. S. P. Co. This instrument consists of an ordinary bulb pattern hydrometer, enclosed in a glass tube, attached to which at one end is an india-rubber ball, by compressing which, while the india-rubber tube attached to the other end is held under the electrolyte, the air is forced out, and when the ball is released, the electrolyte enters the tube, and floating the hydrometer, enables the specific gravity to be read off. By again pressing the ball the electrolyte is returned to the cell, the tube being removed from under the liquid before the ball is again allowed to expand. It is also useful for ascertaining the density of the solution at different depths in a cell, as a sample can be drawn from any point.

It is also often necessary to examine the plates closely. This is much facilitated by a small lamp, on a thin stem, attached to two leads (Fig. 19).

This lamp is specially manufactured for putting into the

electrolyte between the plates, and is specially useful for enabling the condition of the plates to be easily seen in lead or lead-lined boxes. It is fitted with flexible connections, with springs to grip to the lead connecting bars of adjacent cells, a 4-volt lamp being used.

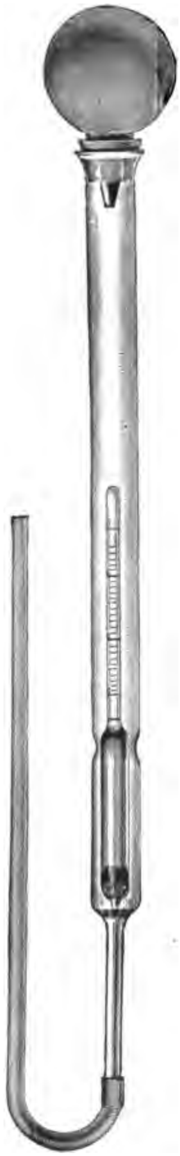


FIG. 18.—Cell Tester for Sp.g.

Fig. 2 illustrates a battery room in the G.P.O., London, 700 K type, E. P. S. cells, which replaced 30,000 primary batteries; and Fig. 1 shows three of the large central station cells complete in their place, in lead-lined wood cases.

The plates of glass on the top are intended to catch acid spray, which rises as a fine mist, especially when charging. This spray can be cleared by good ventilation; battery rooms should be very well ventilated.

Before leaving the subject of batteries it may be interesting to consider the question as to how electricity is to be obtained direct from natural fuel. Answers to this question are at present quite speculative, and there is no practical example of any apparatus capable of producing electricity direct from fuel on any commercial scale, and therefore it might be said that it is useless discussing the subject in a practical work. That is true; but still, on the plea that the subject is the most important at present before the world of science, I propose to briefly refer to the principles of the subject.

The thermopile may at once be dismissed, as it does not convert the energy directly into electrical energy. The energy given out by the combination of fuel is first converted into heat, and then a small portion of this heat is in the thermopile converted into electrical energy.

We are then driven back to the galvanic battery, or primary battery, for a solution of the problem.

Now there is one essential action or phenomenon in the primary battery which must be kept steadily in view in all designs, and that is, the fuel combines with one element of the electrolyte separated from another or other elements, while the separated element left free appears at the opposite plate or pole in the cell some distance away, perhaps even in another vessel.

In the simplest cell—a copper zinc couple in dilute sulphuric acid—the zinc is consumed as fuel, becoming zinc sulphate; the hydrogen

liberated does not appear at the place of decomposition, but at the copper plate only.

And so with electrolysis generally, the separated elements of the electrolytic appear at places a long distance apart.

It may be taken as a rule, without going into the matter deeper, that in any primary battery the elements separated in the electrolyte, one of which combines with the fuel or corroded plate, appear only at the two plates if electric pressure is to be generated instead of heat.

FIG. 19.—Cell Inspection Lamp

If both electrolytic elements separated appear at the separating plate—say, the zinc—then heat is generated instead of electric pressure.

Thus zinc, thrust into hydrochloric acid solution in water, is consumed, separating the chlorine which combines with the zinc, and hydrogen escapes from the zinc surface in torrents producing great heat; a copper plate in the acid, coupled to the zinc, increases the action and a current is produced, but small in proportion to the zinc consumed, the energy being largely converted into heat.

A compound solution may be an electrolyte in so far as it is decomposable by an applied electric current, and yet it may be of no use as an electrolyte in a primary cell; it is therefore not to be supposed that all electrolytes may be electrolised with liberation of electrical energy in a primary cell. By electrolised is meant the separation of the elements of the compound solution, one kind appearing at one plate and the other kind combining with the other or fuel plate.

Thus many fused oxides and other compounds can be electrolised in a decomposition cell, but will not act as electrolytes in a primary cell.

A cell invented by a Mr. Jacques, shown in diagram in Fig. 20, will enable us to examine the question from a fundamental point of view.

Primary Carbon Cell

On this earth we have only two plentiful cheap sources of energy—the oxygen in the atmosphere, and the carbon in the coal fields, oil wells, and in forests, woods, and plants. Therefore we must endeavour to use these elements in generating electric pressure. Many proposals have been made. A gas battery suggests one, using the atmospheric oxygen at one plate and hydrogen or hydro-carbon gases at the other. As these gases are easily produced from coal or wood, this is a quite rational proposal, but no scheme for its practical realisation has been shown.

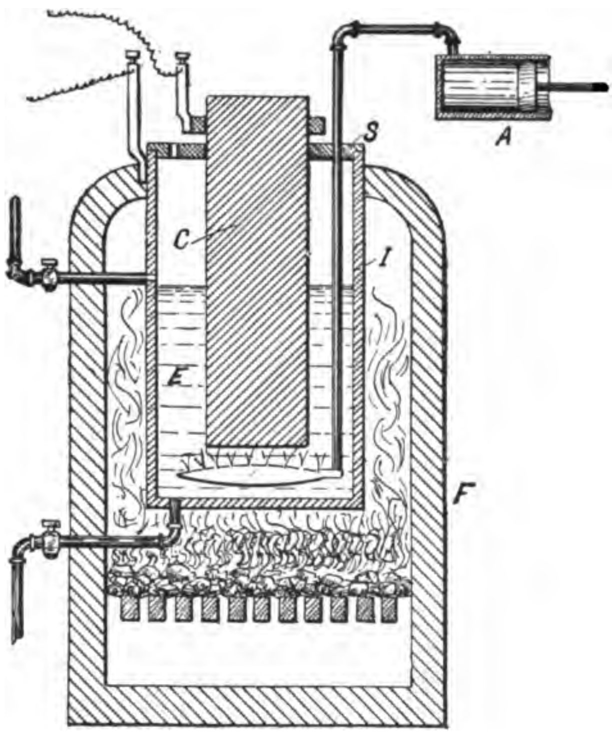


FIG. 20.—Jacques' Battery

The next proposal is that of Jacques to use solid carbon as the fuel plate, and an oxide electrolyte, capable of regeneration by oxygen from the atmosphere, and thus a primary battery could be made requiring only a supply of air and carbon. But Jacques' battery fails to work, and that failure is very instructive; hence it is treated here, and illustrated, for it is quite possible that the missing link required to make it a success may be found, and, as often remarked, success is always obtained by a series of trials and errors, succeeding inventors beginning where their predecessors left off.

We will not follow Jacques' specification closely, as it is not in itself of importance. The electrolytic is a fused oxide—say litharge or oxide of lead; a fire is necessary to fuse it, the outer case of the cell I is therefore of iron and dips into a furnace F, fused litharge E is in the cell, and the fuel plate C a carbon block, and an air pump H pumps air into the fused electrolyte.

Now the idea is, that the oxygen of the litharge Pb,O, will combine with the carbon, and the liberated lead metal will be reoxidised by the oxygen of the injected air, and so the action will go on by merely supplying carbon and air; but the action, so far as it does

go on, does not produce electrical energy, for the oxygen separated from the lead at the carbon, combines with the carbon to form heat; the carbon simply burns away, and the separated lead does not appear on the outer cell, I, as it should if electric action took place, but at the carbon, where its recombination with incoming oxygen also produces only heat.

The conception is grand, but the practice is a miserable failure. What is required is to find an electrolyte in which one element will combine with the carbon, and the freed element will appear on the inner surface of the outer plate or cell, I, to be reoxidised by the oxygen of the incoming air; that is the missing link. It is doubtful if any fused oxide will act in the required way.

Quite recently some details of a new battery for storage purposes have been published. An invention of Mr. Edison, in which salts of nickel are used instead of lead, it has been in use privately for some time, and it is claimed as an improvement over the lead cells. And there seems to be good ground for the claim, as steel may be used for grids, a metal lighter and stronger than lead. The solution is alkaline. The only perceptible drawback is lower voltage, thus requiring more cells; but its small weight and great strength of materials should more than compensate for that. Its introduction into the market is looked forward to with lively interest.

CHAPTER II

PRIME MOVERS

THE present-day electric pressure generator is a steam, oil, gas, water, or wind motor, combined with an electric dynamo. The one is as essential and important as the other. But while the engine may be useful without the dynamo, the dynamo is useless without the engine. The close study of prime movers in the shape of engines is therefore of great importance to the electrical engineer.

The steam-engine has been very slow in its progress, especially in these directions most required, when its power is to be directly converted into electrical energy—high economy at all loads, perfectly regular speed and torque, and absolutely reliable governing.

Twenty years ago, steam engineers were very easily satisfied on these points, especially in governors; they did not know how to govern an engine which was liable at one instantaneous blow to have its whole load thrown off or on. As a rule, the old engines were harnessed up to a mill or factory in which the shafting and belting and gear kept on a load of from 50 to 75 per cent. of the whole load; in fact, it cost just about as much to run them when not a single worker was in the mill as it did when every hand was on the job. The governor, in these cases, was much more ornamental than useful. In fact, to the casual observer, the old pendulum governor, beautifully polished—"highly finished," in present-day language—leisurely swinging around, looked the most scientific and important part of the engine. As a rule they were "badly finished"; their joints too small and rickety, they only served to moderate the variations in speed due to the small possible variations in load.

In these early days, the electrical engineer had an exciting time over his engine experiences, especially when he was in luck and had an engine provided specially to run his dynamo. Sometimes it was fairly good, in the shape of an agricultural portable engine fitted with a Wilson-Hartnell expansion governor, sometimes a horizontal engine with a Porter-Allen governor; and if he was specially favoured with a simple throttle governor, a "Pickering" was not to be despised. In many cases, some old horizontal engine was resurrected from the scrap heap, to run at the terrific speed of sixty revolutions per minute, with a fly-wheel, not turned up, to act as belt pulley. The "governors" were carefully polished up, the "cylinders" got a coat of paint, and there you were, with an electric light engine

any electrical engineer might be proud of. It was a blessing for him switches were few and far between, and fuses bridged over by copper wires, for then he felt that the load could not be altered much without his knowing of it in time to stand by the engine to take on the duties of the "governors."

So long as the load was steady, and the man at the "boiler" kept the steam steady, the result was very beautiful; but, if the load or the fireman were tampered with, the conduct of the ancient engine was erratic and deplorable. Then sometimes the early pioneer would come across a man with a surplus of engine-power, who could see his way to put down a dynamo to be driven from the mill shafting for electric lighting, thus utilising the surplus power. Where there happened to be a steady load this was a success; but in most cases the lights were unsteady—one could count the revolutions of the engine by observing the waxing and waning of the lights.

As the engines were all of slow speed, belt driving was the common practice for all dynamos.

The first high speed direct driven dynamos were run by Brotherhood's three-cylinder engines, or by rotary engines. Then we had the introduction of the vertical inverted cylinder engine, going at moderate speeds, made by Gwynne, Allen, Tangye, Robey, and Marshall. The single-acting engine was introduced by Westinghouse, and made by Alley & M'Lellan. Another single-acting engine which met with great success was introduced by Willans; perhaps more of this type than any other have been used in electrical work. Then the steam-turbine came, by Parsons and De Lavalle.

Belt driving, for all but the smallest plants, has become very rare; for, among all these engines, we can get speeds from 150 to 10,000, and direct driven dynamos are common at speeds of 100 per minute and less.

The gas-engine has had its trials, too, and there are indications that it will come forward more than it has done in the past. The efficiency must be higher in an internal combustion engine than in a steam-engine. The author has always had a feeling that the steam-engine required far too many accessories to obtain its best results. The boiler and its chimney stalk are reminiscent of barbarism. The gas-engine will prevail yet, and then the hideous chimney will disappear. It may take time, but the day will come when the steam-engine will be superseded, with its condensers, pumps, boilers, economisers, water coolers and reservoirs, coal pile, ash-heap, and all the other many details necessary for its operation.

In the internal combustion engine we have the great benefit of energy liberated in the working cylinder itself, and that is a great step in advance of steam-engines.

The steam-turbine is also a step in advance of the piston engine, with its reciprocating motions. The purely rotary motion is certain to tell in competition, and it only now remains to combine the two advantages by making internal combustion turbines. Such a turbine, connected direct to a dynamo, would go a long way towards solving the problem of the direct conversion of energy into electrical energy.

The water-turbine is limited to certain districts where cheap water-power is available. Every water-power is not cheap; in many places water-power is dearer than steam or gas-engine power. In Britain water-power is an insignificant quantity so far as industrial supply is concerned. Tidal power is worthless, as it can only be got by utilising large tracts of land which would be more profitably employed in growing cabbages or other agricultural work.

Wind-power is worthy of consideration. No one as yet has contrived to secure any privileges over the wind; it is free, and its utilisation as a motive force does not require the occupation of much land nor the necessity for great engineering operations like water. It is, however, very variable, so that some means of storage is necessary, to draw upon in times of calm weather.

Electrical storage is not suitable during all the time of wind-power, but by combined dynamos it can be used over a fairly long range.

The wind-motor is a drowned turbine, and ought to be treated as a turbine with a fluid pressure greater on one side than on the other. But at best the power is not great, and, as a power, is only to be used in country places where other powers are not available.

Liquid and solid air has been proposed, in place of compressed air, as a power; but, like compressed air, it must be reheated for economical use, and this reheating is just the difficulty that enthusiastic but ill-informed people do not anticipate. Forgetting or ignoring the fundamental fact that to convert a solid into a liquid, and a liquid into a gas, requires an amount of heat expended for no return whatever in power, and the amount of heat required to raise the liquid air to a gas at a temperature of 212° Fahr. or more before it can do any work in an engine is a very considerable quantity. Liquid air can return to the gaseous form only at a rate dependent upon the quantity of heat supplied, and this heat must be supplied from a furnace or fire. Liquid air is produced by extracting so much energy from air as to reduce its bulk to liquid form, and power is expended in extracting the energy. All that energy must be given back to the liquid air to make it a gas again, and so much more energy given to it in the form of heat as is required in the engine. The engine is then only a fluid pressure engine, in which the pressure is produced by heat, same as a steam-engine. The proposal is founded on ignorance, and wild-cat schemes put forward for utilising liquid air as a motive power are about as reasonable as a proposal to feed

a boiler with ice at 100 or more degrees below zero temperature instead of feeding with water as hot as we can get it.

The natural plentiful sources of energy at this period of the earth's existence are the coal fields, natural oil wells, and forests of wood fuel; and, so far as we can see, when these fail we shall have to grow plants or vegetables from which we can manufacture alcohol to be used as a fuel, a fuel to be replenished annually from quick-growing crops.

Apart from speculations, however, we are face to face with the great problems connected with the supply of available energy for all the power required to perform the work of the world. Few people realise the great amount of fuel, or, in other words, power required to supply the demand for artificial lights. In modern times gas and electric light fritter away immense quantities of power. A good gas jet consumes gas equivalent to about the fifth of a horse-power per hour; one 16 C.P. electric light consumes about one-twelfth of a horse-power per hour; and an arc lamp about one horse-power per hour.

The progress of engineering science and art simply means increased consumption of fuel to provide the light, heat, and power required to run modern conveniences and provide for modern life and comfort. Withdraw the fuel supply, and at once the whole fabric of modern civilisation collapses—no steamships, no railways, no power-driven mills or factories; nothing but a return to primitive times of manual and animal power. When we consider the matter of power and light supply from this point of view, we realise the importance of the labours of advanced scientists in their endeavours to discover the better means of utilising the stores of energy provided for us in the earth in the coal-beds.

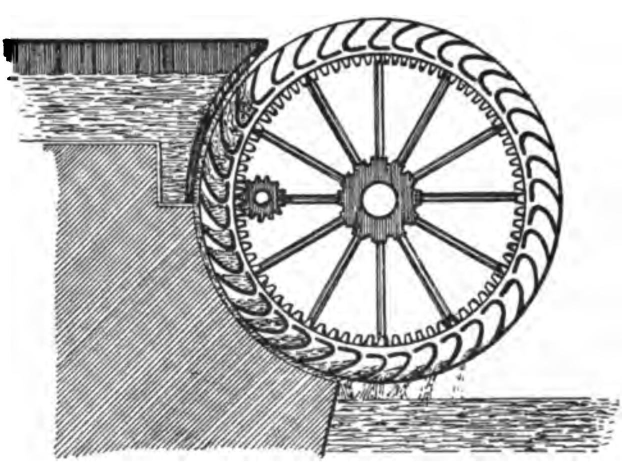


FIG. 21.—Breast Wheel

The commercial production and sale of electrical energy has done more to stimulate efforts towards more efficient methods for obtaining a greater portion of energy from fuel than heretofore, and developments, not now even dimly foreseen, are bound to result from the clearer views opening up on these momentous questions.

Meanwhile, the engineer must do the best he can with the best means at his disposal to accomplish the ends in view, and therefore the engines we have enumerated must form a most essential part of his study.

We may begin with the turbine, as that engine includes water, steam, and wind motors. The water-turbine is the best starting-point, as it is easier understood. Water-power is provided for in two systems, either on a river dammed up, giving a large volume of

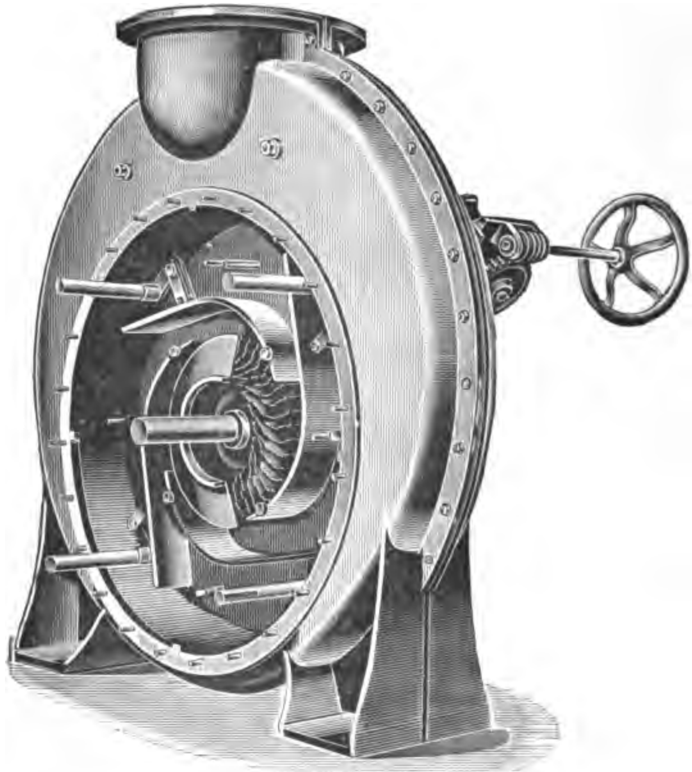


FIG. 22.—Internal arrangement of Vortex-Turbine, showing movable guide blades

water, or a low fall, the utilisation of which requires a very large turbine or wheel. If the fall is not over seven or eight feet, a breast wheel is perhaps the best form of engine. It is shown in Fig. 21 as a diagram. The power is taken off from near the periphery by spur gearing raising the speed, and thus no strain is thrown on the arms of the wheel nor upon the shaft.

River falls are, as a rule, expensive to engineer, land being required, which costs a lot, not to speak of water rights. In Britain there are few falls in places where the power can be used. In Ireland and the north of Scotland there are abundant falls, but situated in places where little use could be made of them.

They might, however, be used to work local light railways to connect to the main lines, and thus open up the country.

The other system is adopted for lighting country residences in hilly districts, where, on most estates, small brooks drain from the hills into some river. A reservoir is made at some height, and the small rills and brooks diverted into it, an outflow passing on the surplus water to the old courses below the reservoir. A pipe line is then run from the reservoir to the lowest available point, and there a dynamo and turbine are driven by the water. The reservoir also provides a service of good water under pressure. On many Scottish and Irish estates a supply of electric light, power, and water can thus

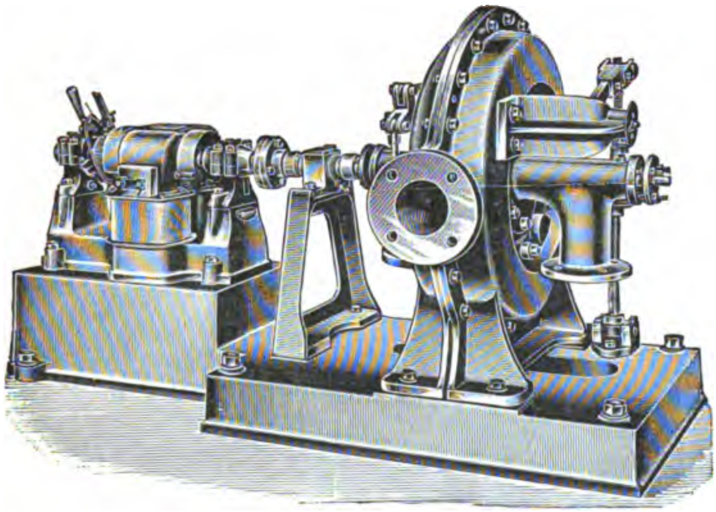


FIG. 23.—Vortex-Turbine, direct-coupled to a Dynamo

be provided at a cost which is not great. The pipe line may be cast-iron, jointed, as is usual for water under pressure.

The best turbine for this purpose is the vortex-turbine, inasmuch as it need not be at the bottom of the fall, but as much as twenty-five feet above; for the water, falling away through a pipe called the draught tube, also works the turbine by suction. Gilkes of Kendall has made this turbine a specialty. It is shown in sectional view, Fig. 22, and complete, attached to a dynamo, in Fig. 23.

Fig. 22 shows how this turbine is regulated by movable gates. These gates are moved out or in by a relay governor, working a piston by the water pressure. The relay governors are of various forms. Fig. 24 illustrates one much used in Switzerland. The governor acts directly on the piston-valve A of a relay cylinder, having a piston with unequal faces. On the lower face the pressure is constant, and would raise the piston if the water on the top could escape. Now, if the governor raises the piston-valve, the water on

top escapes through the valve, and the large piston rises, closing the turbine gates, and so regulating the speed. If the governor drops the piston-valve, the water is admitted from the lower to the upperface, and the upper one being large, the piston falls and opens the turbine gates.

The vortex-turbine is to some extent self-regulating, for the centrifugal effect of the whirling water tends to dam back the incoming water with more force the greater the speed of revolution of the wheel. It is a pressure-turbine, the energy being applied by the pressure of the water.

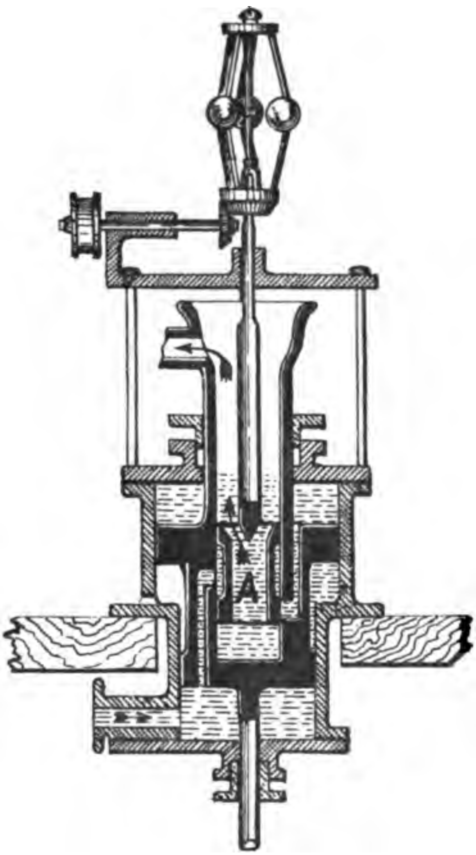


FIG. 24.—Relay Governor for Turbines

In Fig. 25, a portion of this pressure-turbine is shown with the guide blade open, and three of the buckets filled. It is typical of all pressure-turbines; the fluid is pressed through the guide blades and buckets.

In some turbines, such as those represented in Fig. 26, showing two or three buckets only, the water acts by impulse, striking the bucket with full velocity, due to its pressure, and flows freely along the blade without filling the bucket—in fact side vents are in each bucket to allow air to escape from the unfilled portion. In this kind of wheel the water acts by its momentum, due to its weight, multiplied by its velocity.

The impulse-turbine is easier regulated with efficiency than the pressure-turbine, for the efficiency of an impulse wheel is not affected by partial admission of water; hence for electrical generating impulse wheels are preferred where economy of water is necessary.

As to the dimensions of reservoir required, if A be the area of the reservoir in square feet, H the height of the reservoir above the outlet from the wheel, then the amount of power stored is G A H h foot-lbs. ($G = 62.4$ lbs., the weight of a cubic foot of water), hence cubic feet per horse-power hour $= \frac{33000 \times 60}{62.4} = 31,740$, wherein 33,000 is the foot-lbs. per minute in 1 horse-power and 60 the minutes in an hour, $\frac{A\,H\,h}{31740}$ = horse-power hours available; h is the depth of the

water. The volume of water is A h. Thus, if we had 300,000 cubic feet of water at 500 feet level above the wheel, the horse-power hours of storage would be $\frac{500 \times 300000}{31740} = 4725$ horse-power hours.

H is found by surveying the land where a reservoir is required;

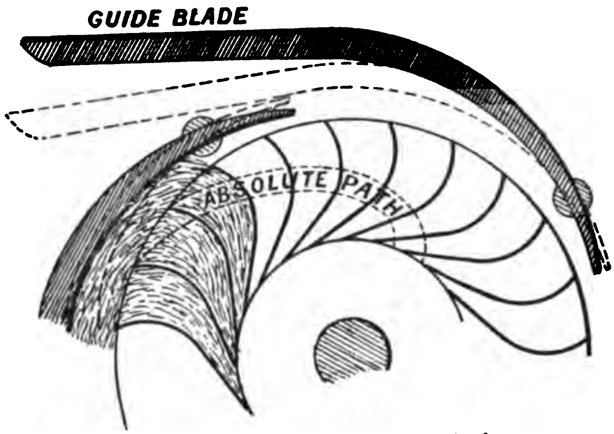


FIG. 25.—Diagram of Vortex Pressure-Turbine

so also is h. The area A can then be calculated for any power required. Thus, if we found a suitable place for a reservoir at a height of 60 feet, and required 20 horse-power hours' storage, then $\frac{A\,H\,h}{31740} = 20$, and $H = 60 \therefore 60\ A\,h = 20 \times 31740 \therefore \frac{20 \times 31740}{60} = A\,h$, the cubic feet capacity $= 10580$ cubic feet, and $\frac{10580}{h} =$ area. Say h is 10 feet, then $A = 1058$ square feet, not a very large area, about $\frac{1}{40}$

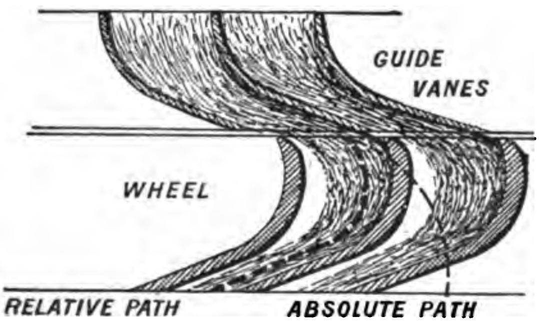


FIG. 26—Diagram of Impulse-Turbine

of an acre; but to make allowance for some surplus and leakage, it is well to make the reservoir larger by 50 per cent.

Twenty horse-power hours would give ten lights for twenty hours, or twenty lights for ten hours.

Water stored in a reservoir, by wind-power pumping it up to a higher level, might in some places be thus utilised, using a series dynamo and motor to work the pump.

Impact or Momentum Turbines

The steam-turbine has at last reached a fairly well-developed standing among motors, and has been realised in the pressure-turbine of Parsons and the impulse-turbine of De Lavalle.

For very high water-pressure the best wheel is the Pelton, shown in Fig. 27. In this wheel the water is discharged as a jet against curved buckets, which turn it back completely, as shown in Fig. 28. The De Lavalle steam-turbine acts in the same way, and the first noticeable feature is the shape of the nozzle from which the steam jet issues. Unlike water, steam expands when issuing from a nozzle, and rapidly for a short distance falls in pressure but gains in velocity ; the

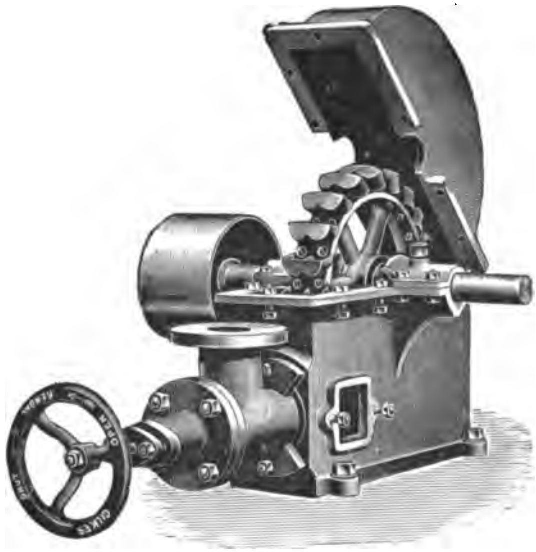


FIG. 27.—Pelton Wheel

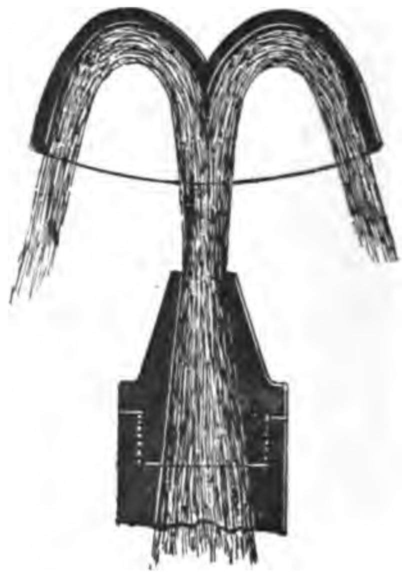


FIG. 28.—Nozzle and Bucket of Pelton Wheel

nozzle is therefore made expanding, as will be seen in Fig. 29, showing a wheel between four nozzles. The nozzle is a cone, in which the steam gains in velocity to the maximum due to the pressure, and falls in pressure to that of the atmosphere in the engine casing just instantly before it strikes the bucket. The weight of the steam is thus thrown against the bucket at an enormous velocity. Steam at 120 lbs. pressure flows at a velocity of 2800 feet per second.

The principle of the De Lavalle turbine is to take up the kinetic energy of a steam jet in the buckets of a turbine wheel against which the steam is blown, thereby imparting a rotary motion, and delivering most of its energy to the rotating wheel. The steam acts by its speed and mass, and before entering the buckets has already been converted to the same pressure as exists in the chamber in which the wheel rotates. To accomplish this, the high-pressure

steam, after it has passed through the governor D (Fig. 30), enters the steam-chamber E, where it is distributed to the steam-nozzles I. These, according to the size of the machine, range in number from 1 to 12. They are fitted with shut-off valves, by means of which one or more nozzles may be cut out when the turbine is not loaded to its full capacity.

This arrangement of utilising the number of nozzles in proportion to the work to be performed allows steam of high boiler

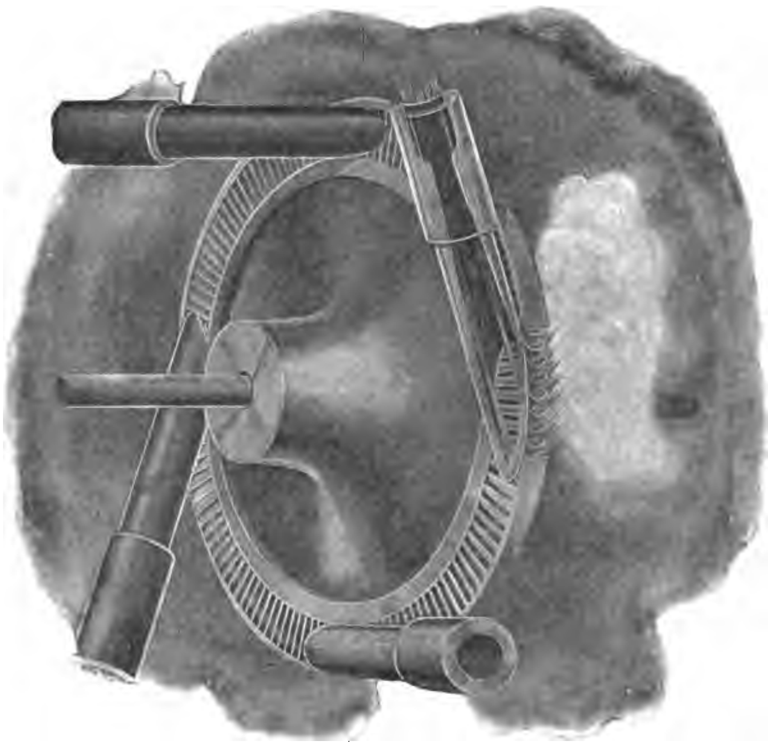


FIG. 29.—Turbine Wheel and Nozzles

pressure to be always used, and adds to the economy on light loads. It also makes it unnecessary for the governor valve to throttle the pressure of the entering steam to any considerable degree. The high speed of the steam is obtained by expanding it; and this expansion takes place in the diverging nozzles. The passage of the nozzles is made conical. This form of construction causes the steam to expand as it passes through the passages, and the work of expansion imparts a very high velocity to the steam as it leaves the nozzles. In a properly constructed nozzle, a volume of steam enters at I gradually; and as every element of the nozzle assumes a temperature constant and equal to that of the passing steam, it

adiabatically expands to minimum pressure; and as this pressure is that of the surrounding medium, the steam at the point of discharge issues in a solid jet without tendency of its particles to divert in any direction.

Table of the Velocity of Outflow and the Working Capacity of Dry Saturated Steam.

Initial Steam Pressure. Pounds per Square Inch.	Counter Pressure, 1 Atmosphere.		
	Velocity of Outflow Steam. Feet per Second.	Kinetic Energy. Foot-pounds per Second.	H.P. of 500 Foot-pounds per Second.
		Per Pound of Steam per Hour.	
100	2717	31.86	0058
120	2822	34.37	0062
140	2913	36.62	0066
160	2992	38.63	0070
180	3058	40.35	0073
200	3115	41.87	0076

The steam, having been completely expanded, is blown through the buckets, and its kinetic energy is transferred to the wheel. After performing its work, the steam passes into the chamber O, and through the exhaust opening N. The angle of the nozzle to the plane of rotation of the wheel is 20°. In such a case, the peripheral speed of the wheel should be nearly half the velocity of the steam; but for practical reasons such a high velocity of the turbine wheel is not used. With steam at 120 lbs. pressure per

Table of Speeds of Steam-Turbine Wheels.

Size of Turbine.	Middle Diameter of Wheel.	Revolutions per Minute.	Peripheral Speed. Feet per Second.
5-H.P.	100 mm. = 4 in.	30,000	515
15-H.P.	150 mm. = 6 in.	24,000	617
30-H.P.	225 mm. = $8\frac{7}{8}$ in.	20,000	774

square inch, the velocity of the outflow steam would be 2822 feet per second, giving a theoretical peripheral speed exceeding 1200 feet per second. The actual speeds adopted are shown in the table.

With the larger turbines, the diameter of the wheel and its peripheral speed are increased, until, with the 300 horse-power, the peripheral speed of the outer rim of the wheel is 1450 feet per

second, or over 16 miles per minute; and this would give a steam consumption of 9.8 lbs. per horse-power. It has been found difficult to produce a material for the wheels that, with an ample margin

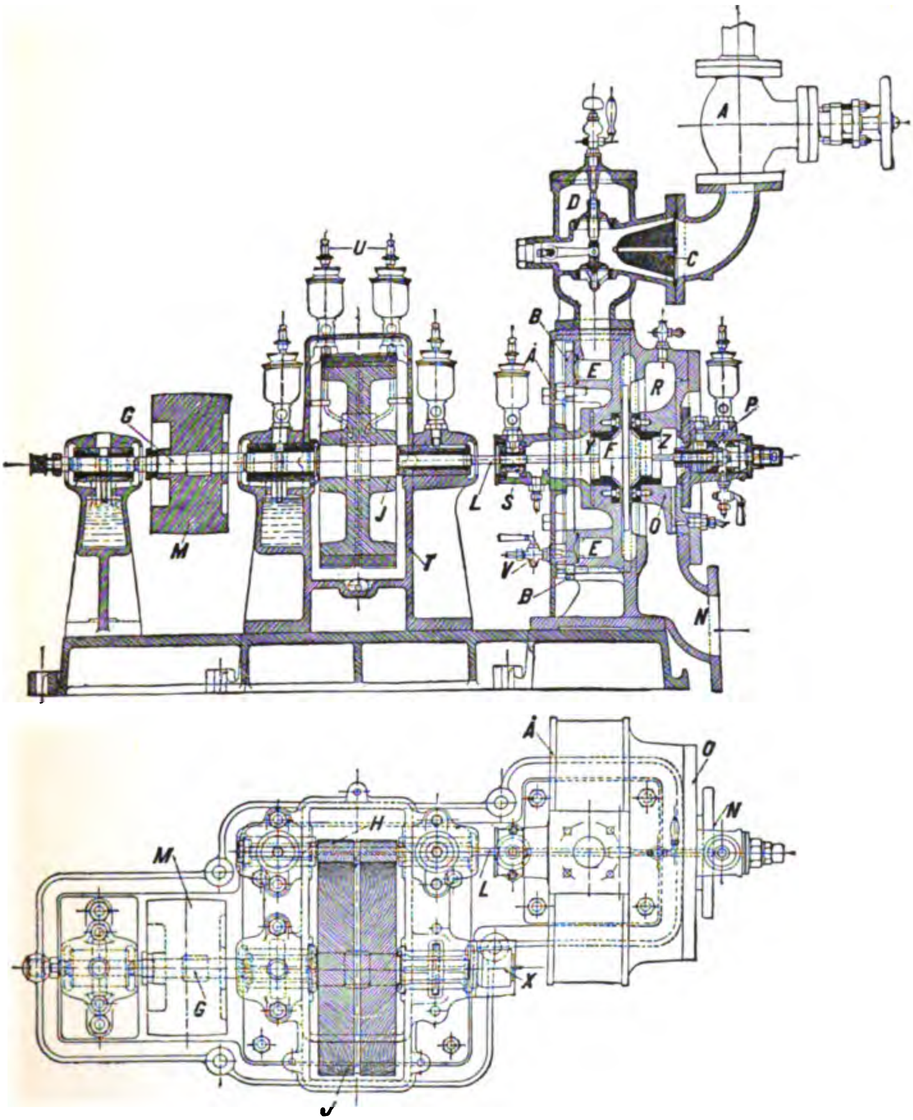
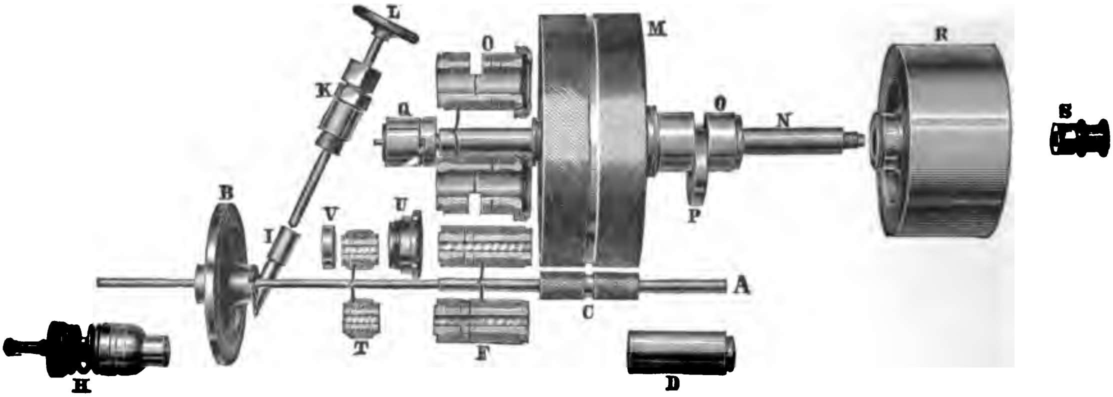


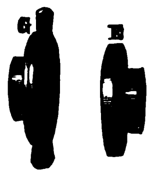
FIG. 30.—Sectional Elevation and Plan of De Lavalle Steam-Turbine

of safety, would withstand the strain produced by the centrifugal force at this high speed. The material now used is nickel steel.

To overcome the impossibility of producing a wheel accurately enough balanced to revolve about its centre of gravity at a speed of

1450 feet per second, without causing a side pressure destructive to plain bearings and a rigid shaft, De Lavalle conceived the flexible shaft, which he has patented. This shaft, bold in idea and ingenious in its application, may be regarded as among the most striking and remarkable inventions in steam engineering; and in its adaptation to the steam-turbine it at once attracts the attention of the constructive engineer. The shaft upon which the turbine wheel is erected is made very slender, which gives it flexibility, and has its bearings far away from the wheel, so that the shaft can





A Turbine shaft
B Turbine wheel
C Pinion
D End bush
E Safety bearing in turbine box
F Middle bush in two parts
G Safety bearing in box covers
H Ball bush with adjusting spring
I Steam nozzle
K Stuffing box with stop valve to nozzle
L Wheel to valve spindle
M Gear wheel
N Gear wheel shaft
O Gear wheel shaft bushes in two parts
P Lubricating ring
Q Centrifugal governor
R Driving pulley
S Stop nut with pulley for connecting to tachometer
T Tightening bush in two parts
U Adjusting nut with spring
V Friction gland

FIG. 31.—Loose Parts of Steam-Turbine

spring and permit the wheel to swing a little in its plane of rotation.

A firm shaft, with bearings near to the wheel, has been found impossible in practice, because the most careful turning cannot bring the centre of gravity of the wheel exactly in its geometrical centre; and the fault causes vibration, which immediately destroys the bearings. On the other hand, when the wheel is mounted on a flexible shaft, there will also be vibrations; and these must increase with the speed. At a certain speed, however, the phenomenon arises that the wheel takes a new centre of rotation very near its centre of gravity. The more the speed is afterwards increased, the nearer will be the centre of rotation to the centre of gravity.

The speed at which the wheel rotates when the before-mentioned phenomenon occurs, is called the "critical" speed of the wheel; and,

having passed this speed, the vibration disappears, and the shaft afterwards runs smoothly in its bearings. This critical speed occurs well below the normal speed of the turbine, and marks the disappearance of all vibration. The machines are usually driven at a speed of 25,000 revolutions per minute, running perfectly smooth and cool at the end of a long day's work. The shaft is supported in three bearings; D and E (Fig. 31) being the pinion bearings, and H the main-shaft bearing, which carries the greater part of the weight of the wheel. There is an additional bearing, T. This is flexible, being entirely free to oscillate with the shaft before and after the critical speed is passed; and its only purpose is to prevent the escape of steam when running non-condensing.

The foregoing particulars were given by Mr. Child in a paper to the Gas Institute. The following are results of tests made by experts at De Lavalle Works, in Sweden, for a full load test.

The turbine dynamo with which the trial took place was provided with a centrifugal pump coupled to the turbine, and worked directly from one of the inductor shafts. This pump, at a suction height of 14 ft. 9 in., forced the water at a pressure of 11.5 lbs. per square inch through an ejector condenser. The turbine dynamo was placed close to the boiler used during the trial. The steam pipe leading to the turbine was provided with a water strainer. The boiler, which was tubular, and provided with an inside furnace, was fed with water at a temperature of 43° F., and generated steam at 118 lbs. per square inch, which was reduced, however, to 114 lbs. by the throttle valve of the governor.

The trial lasted eight hours without interruption, and the fuel used was "best South Yorkshire steam coal," of which 1472 lbs. were consumed during the trials, while the steam consumption amounted to 9823 lbs., consequently the ratio of evaporation was $\frac{9823}{1472} = 6.67$. The vacuum was 13 lbs. The temperature of the condensing water was raised by the steam from 34° to 50° F., consequently the quantity of condensing water may be estimated at about sixty-six times the quantity of steam, or 1271 cubic feet per hour. The dynamo developed during the whole trial an average electrical force of 113.4 volts × 324.0 amperes, or $\frac{113.4 \times 324.0}{736}$ equal to 49.92 electrical horse-power, while the number of revolutions of the inductors was 1.506. Hence the result of the trial gave a steam consumption of $\frac{9823}{8 \times 49.92} = 24.5$ lbs. per hour per electrical horse-power.

For a test at various loads, the following results were obtained:—

One of the steam nozzles was taken out and inserted into a separate steam pipe leading from the nozzle-case to a vessel containing a quantity of water, the weight of which had been ascer-

tained. The vessel was placed on a sensitive balance so that any increase in weight could immediately and accurately be ascertained. With the same steam pressure the turbine dynamo was driven with five steam nozzles developing an electrical effect of 113.5 volts $\times$ 264.2 amperes, equal to an average of 40.74 electrical horse-power. At the same time the steam, which during twelve minutes rushed through the nozzle mentioned above, was condensed, and was found to be 40.5 lbs., or per hour $\frac{60}{12} \times 40.5 = 202$ lbs.

At the end of the trial all of the nozzles were carefully measured and found to be of exactly the same cross section, consequently the quantity of steam which passed through them was 6×202 lbs. = 1212 lbs. per hour. If the steam consumption in section 1 is calculated at the same rate, the result is $\frac{1212}{50.05} = 24.2$ lbs. per hour per electrical horse-power, which differs so very little from the result at the trial on February 15th, during eight hours, that the trifling difference may be owing to a slight variation in taking observations.

As the turbine dynamo, with five steam nozzles open, developed an electrical effect of 40.79 horse-power, and the calculated steam consumption was $5 \times 202 = 1010$ lbs. per hour, in this case the quantity of steam per hour per electrical horse-power would be $\frac{1010}{40.79} = 24.76$ lbs.

At the next test two of the steam nozzles were closed, while the steam pressure remained the same, viz. 114 lbs. The turbine dynamo, with three steam nozzles opened, now developed an electrical power of 113.5 volts $\times$ 140.8 amperes, equal to 21.72 electrical horse-power, while the steam consumption, calculated at the same rate as in the previous case, was 3×202, equal to 606 lbs. per hour, or per electrical horse-power per hour $\frac{606}{21.72}$, equal to 27.9 lbs.

The turbine dynamo was then driven with four steam nozzles open, and the electrical load was regulated to 113.5 volts $\times$ 164.3 amperes, equal to 25.34 electrical horse-power, the steam pressure being reduced by the throttle valve of the governor to 93.8 lbs., with a vacuum of 13.27 lbs. The quantity of steam consumed was measured, and found to be 174.2×4, equal to 696.8 lbs. per hour, consequently per hour per electrical horse-power $\frac{696.8}{25.34}$, equal to 27.49 lbs.

One of the steam nozzles was next closed, so that the turbine dynamo was driven with three steam nozzles open, and the electrical load regulated down to 113.5 volts $\times$ 83.5 amperes, equal to 12.87 electrical horse-power, when the steam pressure was reduced to 74 lbs., with a vacuum of 13.5 ins. On measuring the quantity of

steam consumed, it was found to be $137.28 \times 3 = 411.84$ lbs. per hour, consequently per hour per electrical horse-power $\frac{411.84}{12.87}$, equal to 32.0 lbs.

These are remarkably fine results, and at once brings the steam-turbine into very serious competition with the reciprocating piston engine.

Fig. 32 shows the nozzle, with its stop-valve and part of the wheel buckets.

Fig. 33 shows a turbine coupled to a twin dynamo. The reducing speed gear consists of a right and left handed helical toothed pair of wheels; this acts both as a reducing gear and an end thrust bearing to prevent side play; and to balance the two gears an armature is attached to each shaft. In this turbine is realised the practical success of the "impulse steam-turbine.

Mr. C. A. Parsons has realised the practical success of the

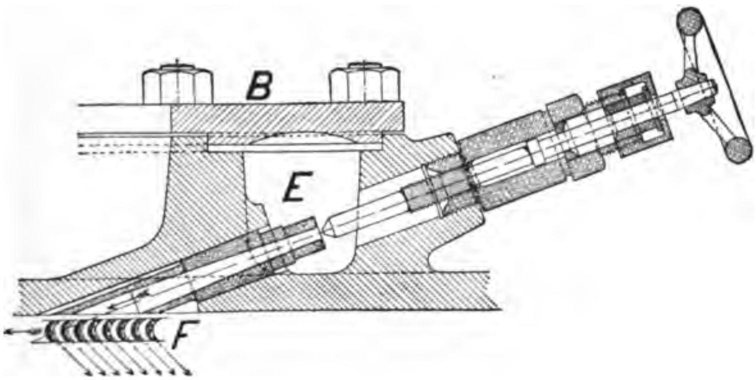


FIG. 32.—Valve and Nozzle of De Lavalle Turbine

pressure steam-turbine shown in section in Fig. 34, and Fig. 35 shows the arrangement of the blades which are used in the turbine. Steam entering at J in Fig. 34 passes through a ring of fixed blades, and is projected in a rotational direction upon the succeeding ring of moving blades, imparting to them a rotational motion. It is then thrown back upon the next ring of guide blades, and the reaction increases the rotational force.

The same process takes place at each of the successive rings of guide and moving blades.

The energy to give the steam its high rotational velocity at each successive ring is applied by the drop in pressure, and the steam expands gradually by small increments.

At the end of the spindle B are grooved pistons or dummies, which fit into corresponding grooves in the cylinder. The object of the dummies is to prevent end thrust, and there is, therefore, a passage in the cylinder between each diameter of the spindle and

dummy of the same size. The dummies also act as a practically steam-tight joint, since the clearance between the grooves can

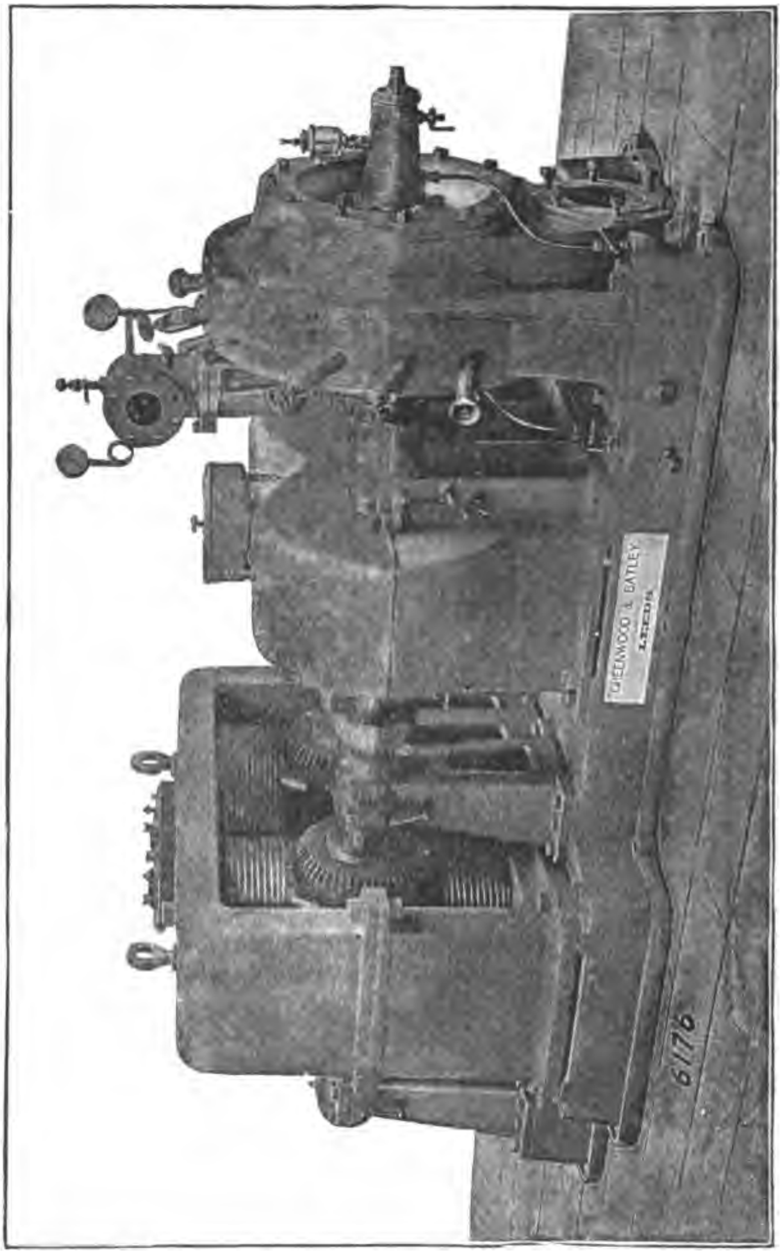


FIG. 33.—100 H.-P. De Lavalle Turbo-Dynamo

be adjusted longitudinally by a thrust block in the end oil keep.

The bearings are of the tubular pattern, and, owing to the light

weight of the revolving spindle, the wear is so small that the bearings often run for several years without being touched.

The armature is directly coupled to the motor spindle by means

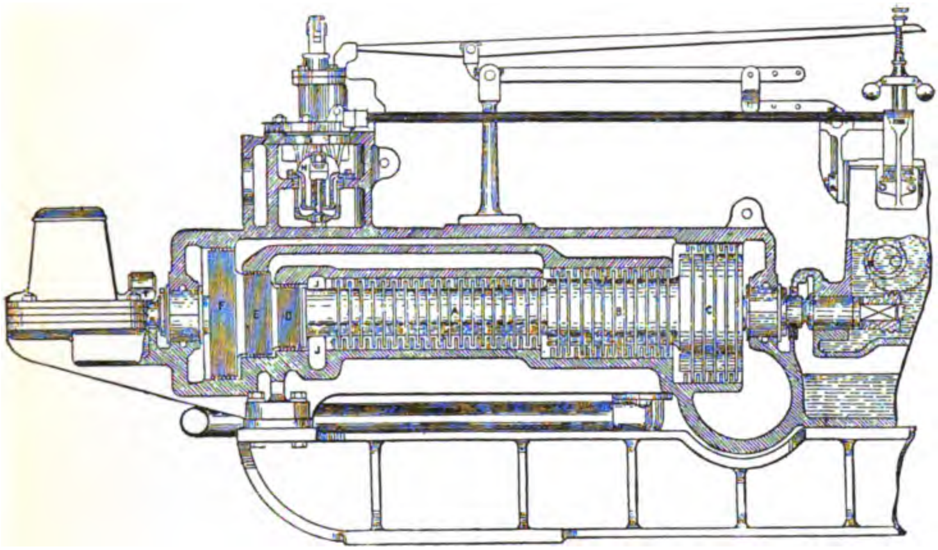


FIG. 34.—Sectional Elevation of Parsons' Steam-Turbine

of a steel sleeve or flexible clutch coupling. The shaft at the other bearing carries a thread, which works a worm wheel, and the worm wheel actuates the oil pump and the steam admission governor by means of an eccentric.

The governing of the machine is accomplished as follows:—Steam is admitted to the turbine in a series of gusts by the periodic closing and opening of a double-beat valve. This valve is operated by means of a steam relay in mechanical connection with the turbine shaft. The duration of each gust is controlled either by an electrical governor, which consists of a solenoid connected as a shunt to the field magnets, the core of the solenoid being hung from the end of the long lever, or by a centrifugal governor driven from a worm on the turbine shaft. The fulcrum of this lever is periodically moved up and down by means of a link connecting it with an eccentric, which receives its motion from the worm on the sleeve coupling; the eccentric also serves to work the oil pump. The short end of the lever controls the valve of the steam relay.

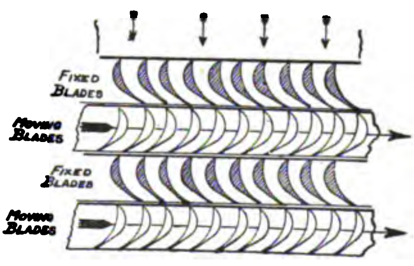


FIG. 35.—Arrangement of Blades

Each periodic movement causes a gust of steam to be admitted to the turbine, the duration of the gust depending on the position of the solenoid in the case of the electrical governor, or the position of the balls in the case of the mechanical governor.

With alternating machines, when governed electrically, an additional series solenoid is placed above the shunt solenoid, the core of the series solenoid being connected to the top side of the long lever; thus, as the load of the dynamo increases, the lever rises and increases the duration of the gusts of steam, and the governor is thus compounded for constant voltage.

The machine is entirely controlled by its governors, either electrical or mechanical, whose action is entirely satisfactory.

The steam-turbine has the following advantages over all other steam-engines :—

(1) The steam consumption, while very low, does not increase with the life of the machine.

(2) At average loads it has a much lower steam consumption than any other engine.

(3) In the large condensing sizes it has a lower steam consumption than any engine at all loads.

So long ago as 1892, Professor Ewing tested a 150 k.w. turbo alternator, condensing type, and reported as follows :—

"A consumption of 27 or 28 lbs. of steam per electrical unit at full load, and 30 or 32 lbs. at half load, is a result that does not need to have its significance emphasised. The efficiency under comparatively small fractions of the full load is probably greater than in any steam-engine, and is a feature of special interest, in relation to the use of the turbine in electric lighting from central stations.

"A consumption of steam at the rate of 28 lbs. per electrical unit is equivalent to 15.7 lbs. of feed water per 'indicated' horse-power hour. Similarly, the steam consumption at half load is equivalent to about 17 lbs. per 'indicated' horse-power hour."

Since this date, great improvements have been made in the efficiency of the turbine. Trials of two engines, built for the Corporation of the city of Elberfeld, in Germany, show a steam consumption of only 18.22 lbs. per K.W., with steam at a temperature of 255° C., and 19.43 lbs., temperature 189° C.; this is equivalent to 10.9 lbs. and 11.6 lbs. per I.H.P., and is perhaps the most economical conversion of steam into electrical power on record.

The steam-turbine has much to recommend its adoption in

electrical generating works, both for large and small work. It has had the usual long, hard-fought battle to win before being recognised as an advance, but few independent engineers can deny that it has at last come to its rightful position as a steam motor of first importance.

The fly-wheel alternator or dynamo on a large slow-going engine is a mighty looking machine, but it always has the look of the

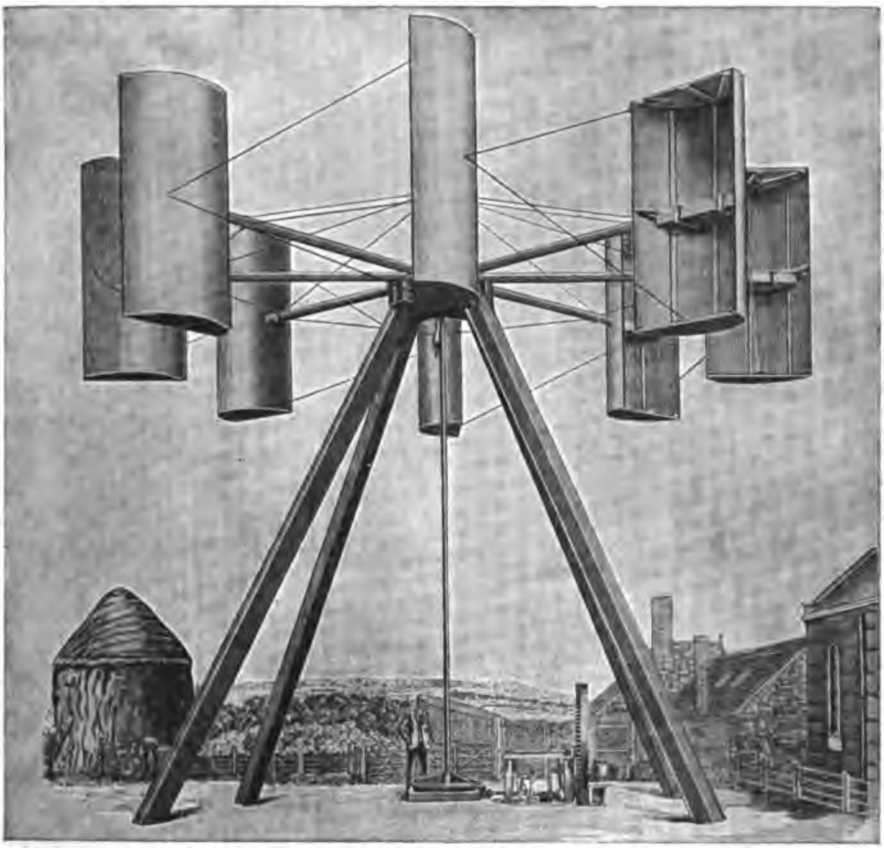


FIG. 36.—Professor Blyth's Windmill

mountain labouring to bring forth a mouse; when one comes to look at the machinery, and the actual results produced, the effect seems small compared with the cause. On the other hand, we have in the turbo-generator a machine every ounce of which is effective, small, compact, strong, and efficient.

Wind-power is familiar to most people in the shape of the picturesque old windmill, with its huge, slowly revolving sails, forming quite an interesting feature in the landscape.

Much might be done to improve windmills, if it were worth

while. We can only refer to one improved wheel here, that of Professor Blyth, of Glasgow, who for years laboured on this subject,

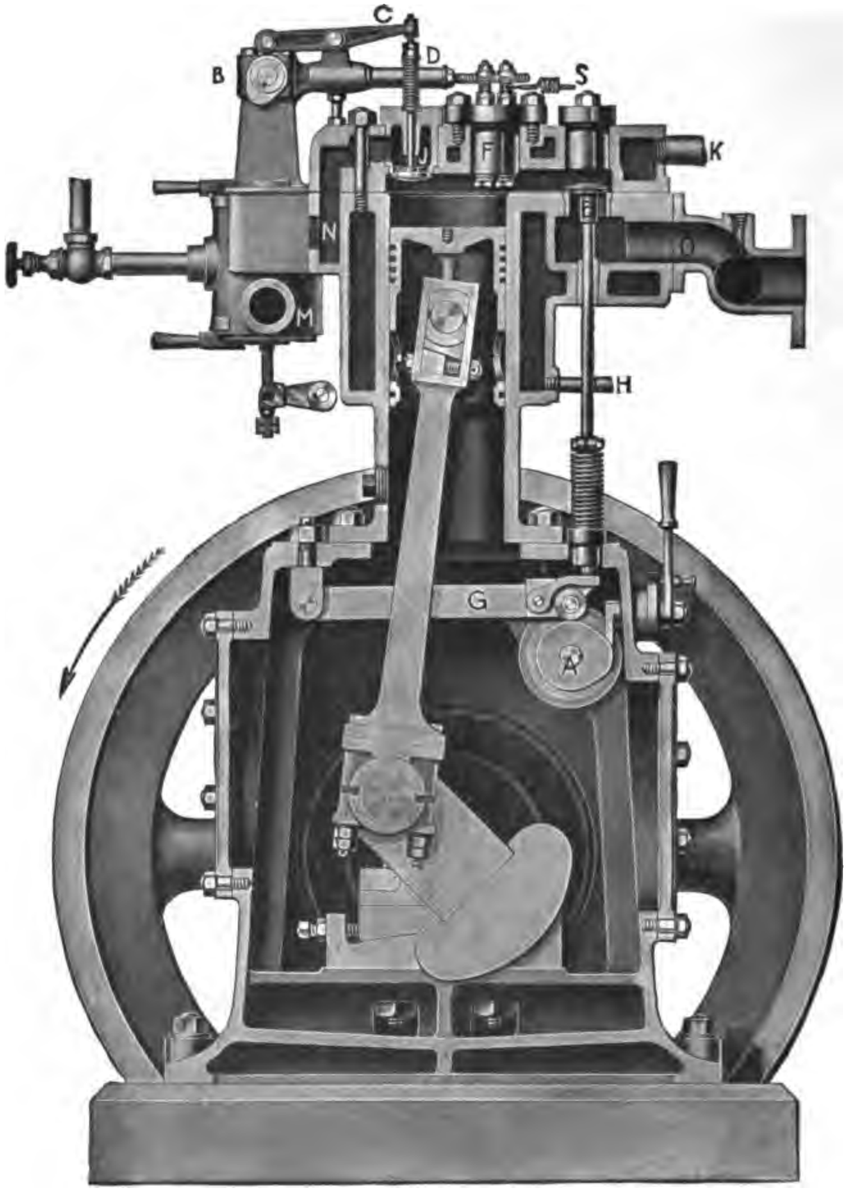


FIG. 37.—Sectional View of Westinghouse Gas-Engine

first for lighting his own house and afterwards for other installations, one of which is shown in Fig. 36. The wheel is an adaptation of the Robinson anemometer for measuring the speed of the wind; the buckets are half cylindrical, carried on horizontal radial arms from a

vertical shaft. It runs with wind blowing in any direction; cannot race, for it always goes somewhat slower than the wind. It has many advantages over the old windmill. In colonial farms and estates it would form a useful power supply, especially with some form of storage provided, as suggested on page 39.

Another powerful rival to the steam-engine is the gas or internal-combustion engine rapidly coming on in competition.

The steam-engine, instead of becoming simplified as time goes on, becomes more complicated. To secure any efficiency the auxiliary plant in connection with the steam-engine is nowadays something formidable. On the engine itself we must have a fine governor automatic cut-off expansion, forced lubrication, compound or triple cylinders, air pumps, condensers, water reservoir or water cooling towers, water purifiers, steam separator, oil filter for steam mechanical stokers, coal elevators, ash hoists, economiser, large boilers, chimney, and other things all following upon the combustion of the fuel in one place and the conversion of the heat in another place into the desired power. Verily, if any man believes "it is better to put up with the ills that we have, than fly to those we know not of," it is the steam engineer.

The internal-combustion engine drops the whole conglomeration above mentioned out of sight, and we find a motor, simple, economical, and effective. And that it is now in the field as a young and healthy competitor can be seen at a glance on Fig. 38, the Westinghouse Company again leading in a new departure in electrical engineering of far-reaching consequences. The vast array of huge machinery, and buildings, and multitude of accessories required for modern steam plants are becoming intolerable, and the next generation of engineers in all likelihood will abandon steam in electrical generating altogether.

The Westinghouse engine is described as follows. Fig. 37 shows a section through one cylinder of the engine. The cylinders are mounted on an enclosed crank case, forming the base of the engine and oil chamber for lubricating the cranks and connecting rod. The engine is single-acting, a feature which has been regarded as desirable in a steam-engine, but which is absolutely necessary in a gas-engine, for the reason that stuffing boxes and piston-rods deteriorate too rapidly when the latter are exposed for half the time to an atmosphere of burning gases.

A simple trunk piston of generous length, carrying a hardened steel wrist pin, which is linked to the crank by the connecting rod, comprises the mechanism for transforming the intermittent pressures on the top of the piston into rotary motion at the shaft. In this respect the Westinghouse gas-engine does not differ from the most elementary steam-engine.

Westinghouse Gas-Engines

The feature about a gas-engine which gives an impression that it is a complicated machine is the train of gearing used for driving the valve motion. When it is understood just why this gearing is

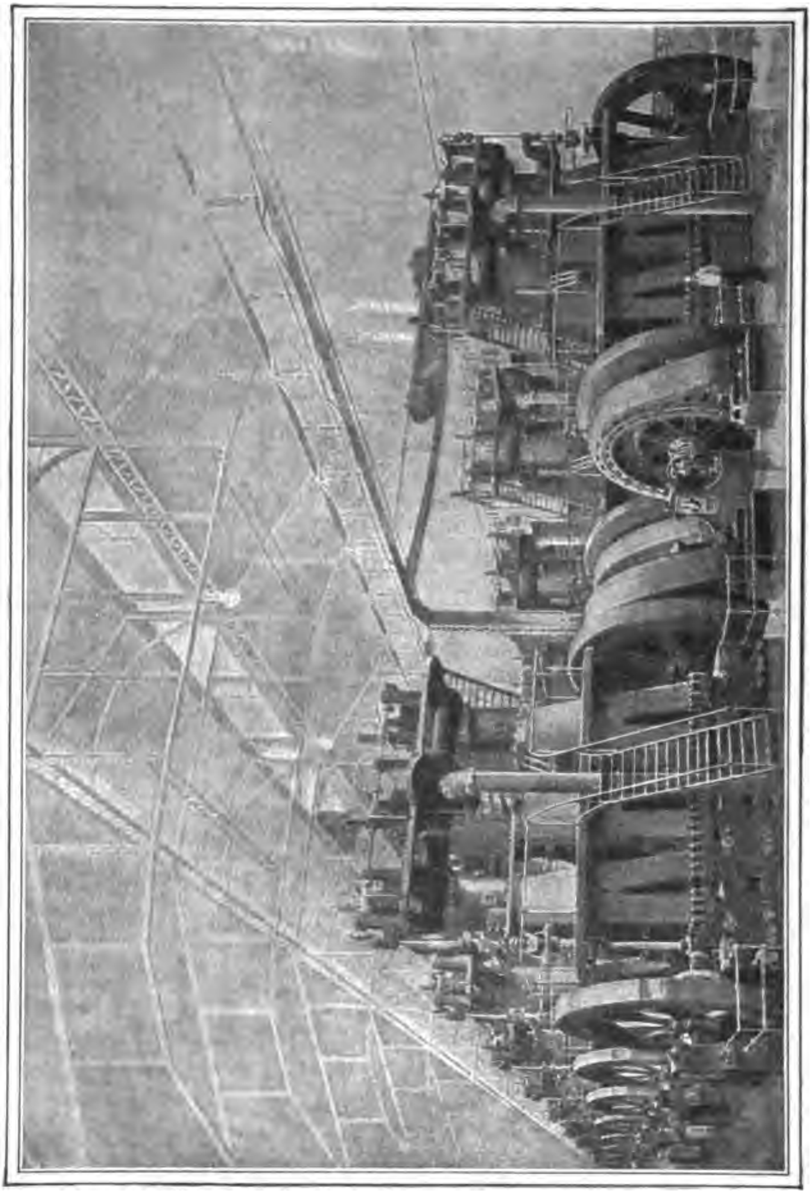


Fig. 38.—30,000 H.-P. Gas-Engine Electric Station, each Unit 2500 H.-P., by Westinghouse Co.

required, and what purpose it serves, the impression of complication disappears, as gearing in itself is one of the oldest and most familiar elements of machinery. In order to make the utility of the train of

gears apparent, it is necessary to consider what takes place in the cylinder. As the gas must burn in the enclosed space between the piston and the cylinder head, it must first be mixed with such an amount of air as will furnish sufficient oxygen for its rapid and complete combustion. If the air supply be too little, the gas is not all consumed, and the economy is thereby seriously impaired, and if the air supply be too great, the quantity of gas used per stroke is reduced, resulting in lowering the capacity of the engine.

The piston being at the top of its stroke and moving downward, draws in a cylinder full of the mixture of gas and air. On the return stroke this charge is compressed into the clearance space between the top of the piston and the cylinder head. The smaller this clearance, and consequently the higher the compression, the more efficient the engine, the reason being that with a measured quantity of gas, such as is contained in a cylinder full of the mixture, the smaller the space in which it is burned the higher will be the pressure generated, and the smaller the initial volume of the products of combustion under the high pressure, the greater number of times they will be expanded in following up the piston to the end of its working stroke.

Referring again to the sectional view (Fig. 37), A is the shaft which carries the exhaust valve cams, and is driven by gears from the main shaft. Each exhaust cam works against a roller carried on the free end of the guide lever (G). The exhaust valve (E) has a long stem projecting downward and resting on a hardened steel plate on the upper side of the guide lever (G). The spring surrounding the stem serves to hold the exhaust valve to its seat and the stem in contact with the guide lever. From the exhaust cam shaft (A) a horizontal shaft with bevel gears leads to the opposite side of the engine, engaging with a vertical shaft which in turn drives the upper cam shaft (B). Incidentally, the vertical shaft carries the governor. The upper cam shaft carries two cams for each cylinder. One engages against a roller on the end of the horizontal lever (C). As the throw side of this cam comes uppermost, the opposite end of the lever (C) depresses the stem of the inlet valve (J), opening the latter for the admission of the mixture of gas and air. A spring on the stem of the inlet valve furnishes a means for closing it, and keeping the cam and roller always in contact with each other. Immediately adjacent to the inlet valve cam is the ignitor cam, which at the proper instant operates a horizontal plunger working through the guide (D) to break the electric current through the wire (S) at the terminals of the ignitor (F).

The cylinder heads and the upper end of the cylinder are thoroughly water-jacketed, as, owing to the extreme heat to which these parts are subjected, they would soon become red-hot if no

means were provided for keeping the temperature down. The cooling water enters at H and is discharged at K.

The governing of large gas-engines is quite as important as the governing of steam-engines. The Westinghouse Company claim specially good results in this respect, compared with the hit-and-miss principle.

Hit-and-miss engines are particularly unsuited for the exacting requirements of electric lighting, especially since the advent of high efficiency lamps, on which the effects of poor speed regulation are disastrous. Even though the utmost care be exercised in installing a lighting plant driven by such an engine, and the fly-wheels of the engine be supplemented, as is usually the case, by others on a jack shaft or on the shaft of the dynamo itself, the explosions in the cylinder can easily be counted by the fluctuations in the brilliancy of the lights.

The frequency of the impulses is the same for all loads, and the relative proportions of gas and air remain constant, but the amount of the charge admitted to the cylinders and the consequent strength of the impulse is graduated exactly to the power required. The nicety of regulation is equalled only by the best types of automatic steam-engines.

The proper proportioning of the air and fuel is also an important factor in the economic performance. The correct proportions are easily and accurately determined, once for all.

The fuel consumption in the larger engines is naturally a little less per horse-power than in smaller ones, but the difference is trifling, the efficiency depending less on the relative size of the units than in any other form of motor known.

The following may be regarded as a fair and conservative statement of the fuel consumption when the engine is running near the rated load :—

Ordinary town gas, 15 to 17 cubic feet per brake horse-power per hour.

Commercial 74° gasolene, $\frac{1}{6}$ to $\frac{1}{8}$ gallon per brake horse-power per hour.

From experiments made at a producer gas plant, the consumption of coal in the producer will not exceed $1\frac{1}{4}$ pounds of coal per brake horse-power per hour, and this will probably be brought down to one pound or less on larger engines.

With the gas-engine the fuel expense begins and ends with the starting and stopping of the engine.

But fuel is only one item of cost in the production of power. Due consideration must be given to the value of the additional space, and the buildings required for a boiler plant; the cost of a stack; the labour of handling coal and ashes; cost of attendance, oil and water; depreciation, repairs, and insurance on boilers.

Gas Producer

Some argue that, notwithstanding the superior thermal efficiency of the gas-engine, a given number of heat units in the form of fuel suitable for burning in the cylinders costs more than an equivalent number of heat units in the shape of coal, or other ordinary fuel suitable for burning in a common boiler furnace, and that, consequently, the usefulness of the gas-engine is limited to small installations where its incidental advantages are considerable, and where a steam plant would be of such insignificant size that its efficiency would naturally be low. Such an argument can, however, be based only on a superficial knowledge of the facts.

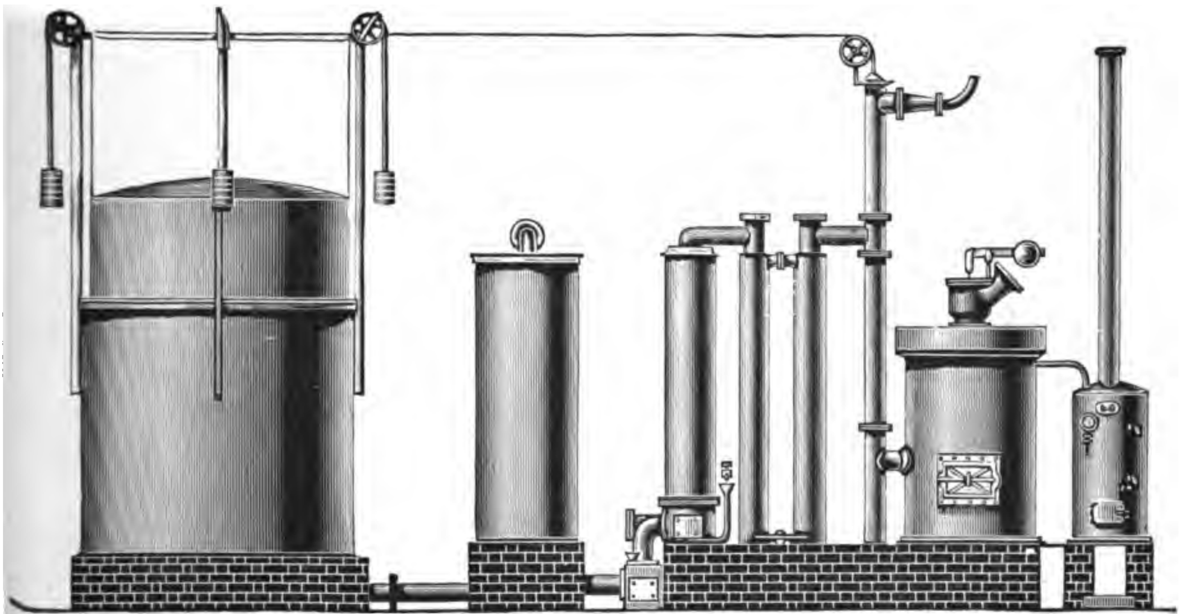


FIG. 39.—Patent Gas-Producing Plant, by J. E. H. Andrew & Co.

The development of gas-engines of large power has opened up new methods of supplying gas fuel to an extent scarcely dreamed of by those not in constant touch with the work. Waste gases from blast-furnaces are now being utilised in gas-engines, developing from four to five times the power that is obtained from the same gases when burned under steam boilers.

Steps are being taken to utilise the millions of horse-power annually going up in flame and smoke from coke ovens all over the world. Gas producers are being built in which the gas carries 80 per cent. of the heat in the fuel—a much larger percentage than is carried by the steam from the most efficient type of boiler known. Fuel gas processes in which the by-products almost, if not entirely, pay the operating expenses are rapidly passing from the domain of theory into that of established fact.

Thus, it will be seen that in considering the relative advantages of the gas-engine and the steam-engine, the problem must be carefully considered in every aspect, and it requires the painstaking care of a well-informed engineer to compare them fairly.

Fig. 40 shows a direct coupled 125 horse-power gas engine and dynamo.

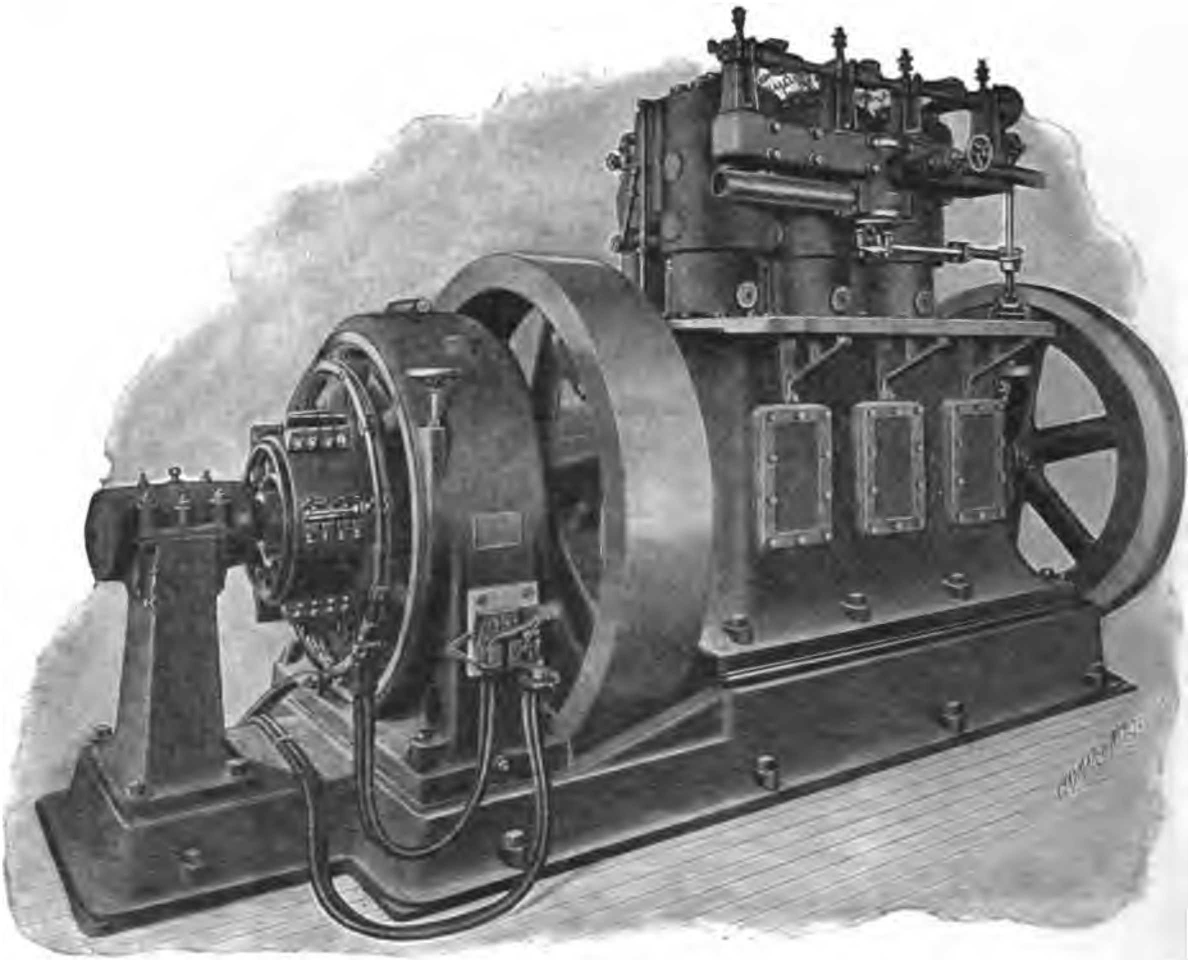


FIG. 40.—125 H.-P. Gas-Engine Plant

Great developments are going on at Trafford Park, Manchester, in the way of distributing cheap gas made on Dr. Mond's process, whereby power can be got from gas-engines at a cost far below that of steam. There are many systems for producing cheap gas into which we cannot here inquire. But an illustration (Fig. 39) of one may be of interest, as supplied by Messrs. J. E. H. Andrew, Stockport.

It is guaranteed in large units to give one brake horse-power on 1 lb. of anthracite coal per hour. Steam from a small boiler is blown through the incandescent coal in the furnace, and is decomposed, producing gas which passes through coolers and a scrubber to a gas holder, from which it is drawn for the engines.

In the Mond process common coal slack is used.

Fig. 41 represents the Stockport combined engine and dynamo,

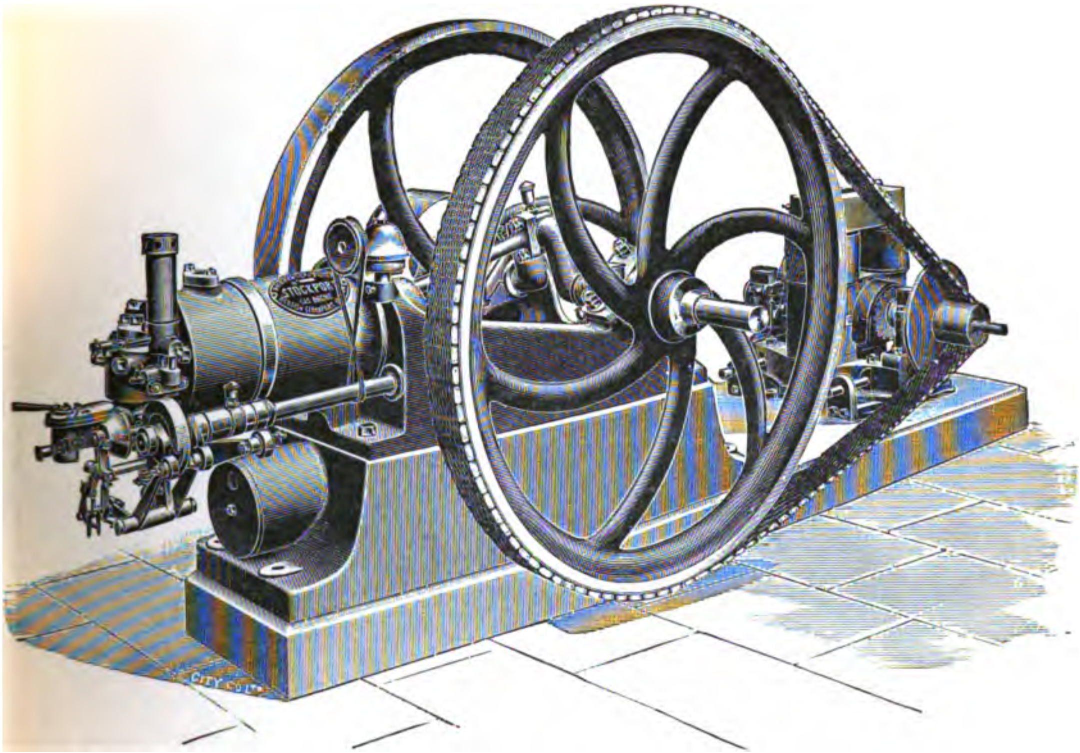


FIG. 41.—"Stockport" Gas-Engine and Dynamo, Belt Driven

belt driven; they also make large horizontal gas-engines, as shown in Fig. 42, with very massive fly-wheels, for electric light driving.

The whole question of gas-power is very interesting, and worthy of the closest attention by engineers.

It may be said that gas plants on a large scale have not hitherto been successful in this country. Well, the same may be said of a good many steam plants, and the failures in both cases can hardly be altogether laid to the discredit of the engines employed.

Of course the gas-engine requires the gas producer and a supply of cold water for the cylinders, but these are not of the same magnitude as the auxiliaries of the steam-engine. The gas producer is simple and not under high pressure, and gas can be stored ready

for use at any moment. The water required for cooling is not great, and may be used over and over again, and does not require to be much below boiling point in any case.

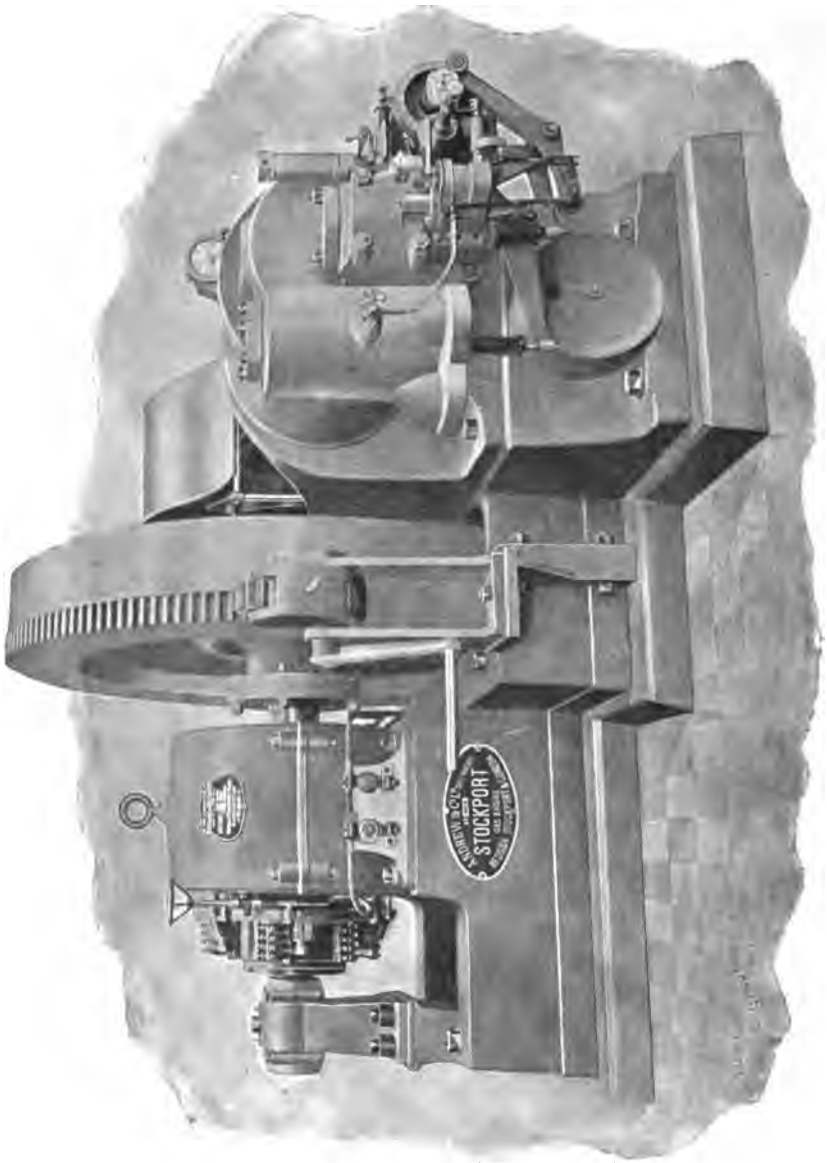


FIG. 42.—Direct-Coupled Gas-Engine and Dynamo

The little oil-engines on motor-cars are marvellous little motors. Their perfection has been the impelling cause of progress in that

industry. Coupled to a dynamo these oil-motors make very convenient little portable plants.

There are other gas and oil-engines of interest to the engineer. Those referred to herein may, however, suffice for our purposes.

The reciprocatory steam-engine is of course the largest power on earth as yet, and being the prime manufacture of engineers of all countries, and many vested interests being involved in its production, is likely to be for long in use, even after it has been far surpassed in the competition by other prime movers. As already pointed out, its efficiency is necessarily low, and the magnitude of the auxiliaries required to attain the best efficiency is great and their numbers many, so that maintenance and attendance become large items.

The large gas-engine as a prime mover for electrical generators has at last "come to stay," when, besides the advances made in large engine construction by the established makers, we find engineering firms like Messrs. Mather & Platt, of Manchester, and the Westinghouse Company, laying themselves out for the manufacture of engines of any power *over* 300 horse-power direct-coupled to dynamos. We may be assured that gas-engines have entered upon the very field hitherto considered as belonging to steam reciprocating engines only.

The dynamo and engine are one machine, designed to turn out a saleable commodity, and naturally the manufacture must eventually fall into the same hands. The present stage, where the engines are made by one firm and the dynamos by another, is gradually changing to the combined manufacture by one firm.

There are, of course, first-class dynamo makers who decline to make engines, and first-class engine makers who decline to make dynamos, so that each can with mutual advantage supply the other; but the firm that makes both must have some commercial advantages, for, consulting engineers and others prefer to have a combined engine and dynamo under one specification and contract.

Fig. 43 represents the Körting gas-engine taken up for manufacture by Messrs. Mather & Platt.

This engine is of the *double-acting two-cycle type*—that is to say, *each* side of the piston receives an impulse at *every* revolution in contradistinction to the single-acting Otto cycle-engine, which receives an impulse on one side of the piston only once in two revolutions; in other words, during the same number of revolutions, the piston of a single-cylinder Körting engine receives just four times as many impulses as does that of a single-cylinder Otto cycle-engine. Thus a much more even turning moment on the crankshaft is obtained, and engines of large power occupy less floor space, and are of less weight than with single-acting Otto cycle-engines. And the cushioning effects of the compression are not to be neglected.

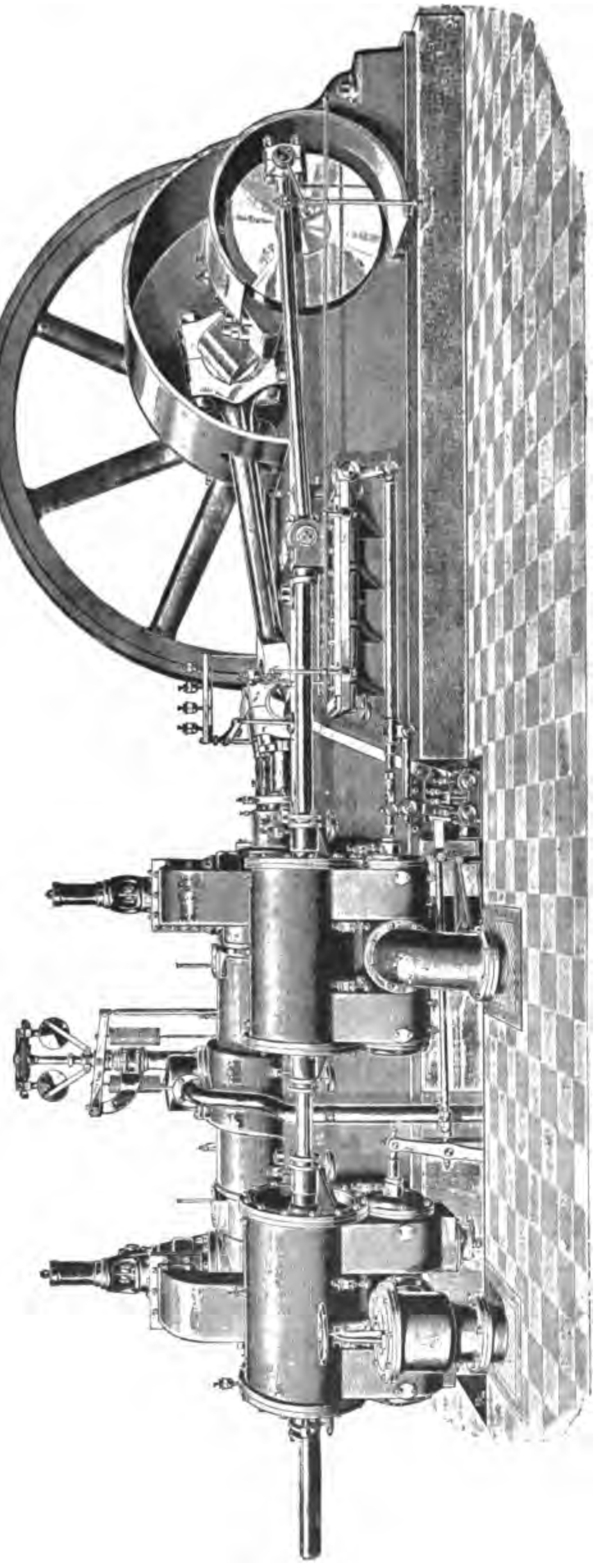


FIG. 43.—"Körting" Gas-Engine, by Mather & Platt

The largest power developed in one cylinder of any gas-engine hitherto manufactured in this country has been about 300 B.H.P.; but they are now prepared to offer engines developing 400, 500, 600, 700, and 1000 B.H.P. in one cylinder, or double these powers in two cylinders.

Also, to construct these engines to work with blast-furnace gas, Mond or other producer gas, or town's gas, and to guarantee their satisfactory working.

The number of engines of the Körting type hitherto constructed, or now on order, represents nearly 45,000 B.H.P., which is a sufficient guarantee of the excellency and reliability of this design.

Messrs. Tangye of Birmingham have also entered the gas-engine manufacture for large powers, adoping an engine on the Otto cycle.

For large powers the double-acting engine other things being equal would seem to have advantages, as its plant

efficiency must be greater than the single-acting engine; but experience alone can decide the question of single-acting versus double-acting gas-engines for large electric generators direct-coupled.

On the whole question of engines, it is clear that the reciprocating steam-engine has passed its meridian. Only by the most elaborate and expensive processes — extra high boiler pressure, condensing, and superheating—can its efficiency as a heat engine approach that of an internal-combustion engine.

And the internal-combustion engine has not yet reached anywhere near its possibilities. Solid and liquid fuels may be burned inside the engine. And we may have internal-combustion turbines in the future—in fact, there is no end to the march of improvements. It is a slow, continual progress, by small steps, marked by periods, where some one more enterprising and far-seeing than his fellows, and with means at his disposal, strikes out a new line, taking advantage of all the experience and knowledge accumulated since the previous period.

The Deisel gas-engine is a new departure which deserves close attention. It is being perfected in this country. Only the principles of it may be here referred to at present. The air and fuel are introduced into the cylinder in carefully measured quantities, and burn gradually as the piston advances, without explosion, the air expanding gradually.

It is much the same as if air and fuel were admitted at high pressure in proper proportion for about one-eighth of the stroke and then fired. The piston would be moving forward with increasing velocity, and the combustion would be slow enough to follow up gradually.

Fig. 44 shows a sectional diagram which may serve to explain the operation of this heat-motor, the frame, connecting rod, fly-wheel, &c., being omitted. There are two combustion cylinders C, provided with plunger pistons P, and joined by means of controlled valves *b* to the two sides of a larger cylinder B; by controlled valves *a* the two combustion cylinders are also in connection with the air vessel L. The cranks of the two cylinders C occupy corresponding positions, and form an angle of 180° with the crank of the cylinder B.

In its upward movement the piston Q draws atmospheric air through the valve *d*, compresses it in the downward movement to several atmospheres, and then forces it through the valve *e* to the air vessel L. The lower part of the cylinder B serves merely as an air pump, and effects the preliminary compression of the air used for the combustion.

As the piston P moves downwards, it draws the air from the vessel L, wherein it is already under pressure, so that in its upward

movement the piston P effects the second stage of the compression to the desired degree. The terminal positions of the piston above and below are shown by dotted lines, and designated by 1 and 2.

Then the piston P moves downwards again to the position 3, while fuel is gradually introduced and burnt. In this instance the fuel used is coal dust, which is introduced into the cylinder during a prescribed period of admission by slowly turning a rotary cock having a lateral groove.

At 3 the admission of fuel is discontinued, and the air expands and completes the stroke. On the piston reaching its lowest position 1. the valve *b* is opened, the piston Q being at the top at this

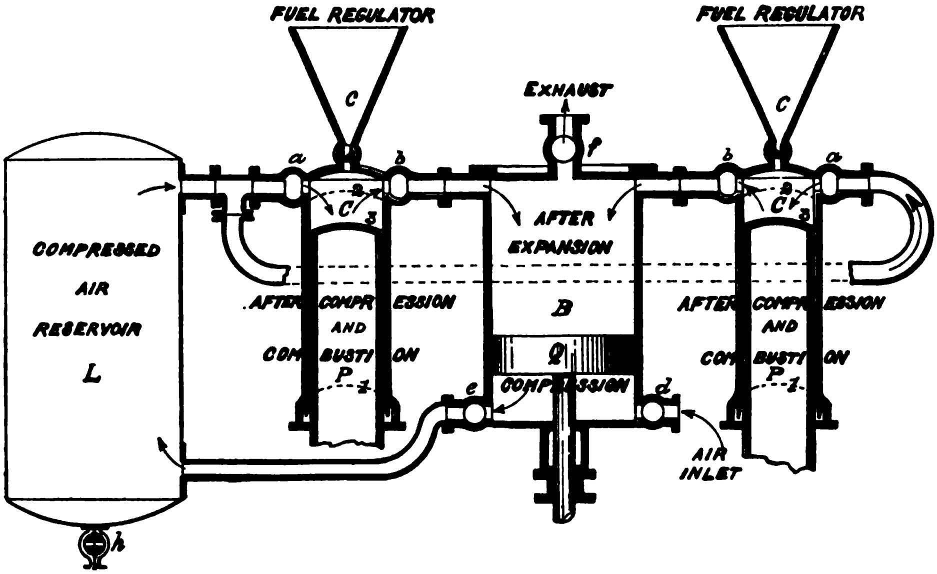
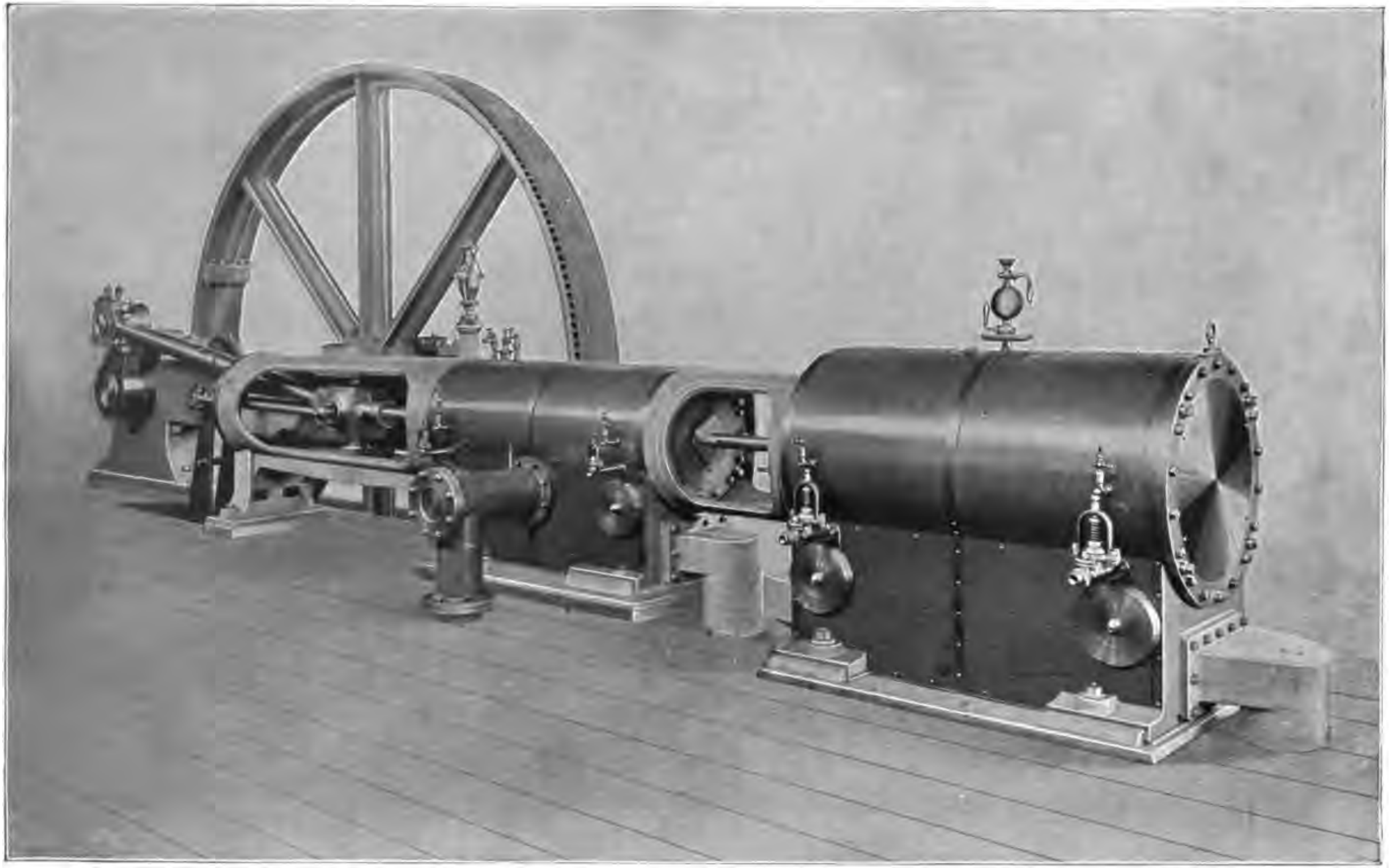


FIG. 44.—Deisel Gas-Engine Diagram

moment. In the further operation the piston P moves upwards, and the piston Q downwards, the gases expanding to the volume of the cylinder B. After this, the valve *b* is closed, and the valve *f* opened, so that during the next upward movement of the piston Q the gases will be discharged through the valve *f* into the atmosphere.

The reciprocatory steam-engine is still the most commonly used motor for dynamos—in two types, high speeds from 250 to 500 revolutions per minute, and low speeds from 100 to 200 revolutions per minute. Belt and rope driving from an engine is now a practice of the past.

The slow-speed engine and dynamo combination is used for large units, and is likely to be for some time a type for units of 1000 K.W. and upwards. Both horizontal and vertical engines are employed as motors. Where space is unlimited such large direct



Tandem Compound Engine. (Daniel Adamson, Manchester)

connected plants are perhaps best, and large generating stations should not on any account be placed where land is not practically unlimited and cheap.

The steam-turbine of the pressure type will, however, in large units, prove a powerful rival to these large, slow-moving reciprocating engines, for the larger these turbines are made the better they are, and so far as the dynamo is concerned, any speed below 5000 has nothing to be said against it. In the case of large fly-wheel dynamos the dynamo is made to suit the engine in speed; it is no better for being big and heavy; it is of necessity large because of the slow speed.

The largest engines are generally horizontal cross compound, and with the dynamo between them. Others are more of the marine engine type, vertical triple expansion, with the dynamo at one end or a dynamo at both ends.

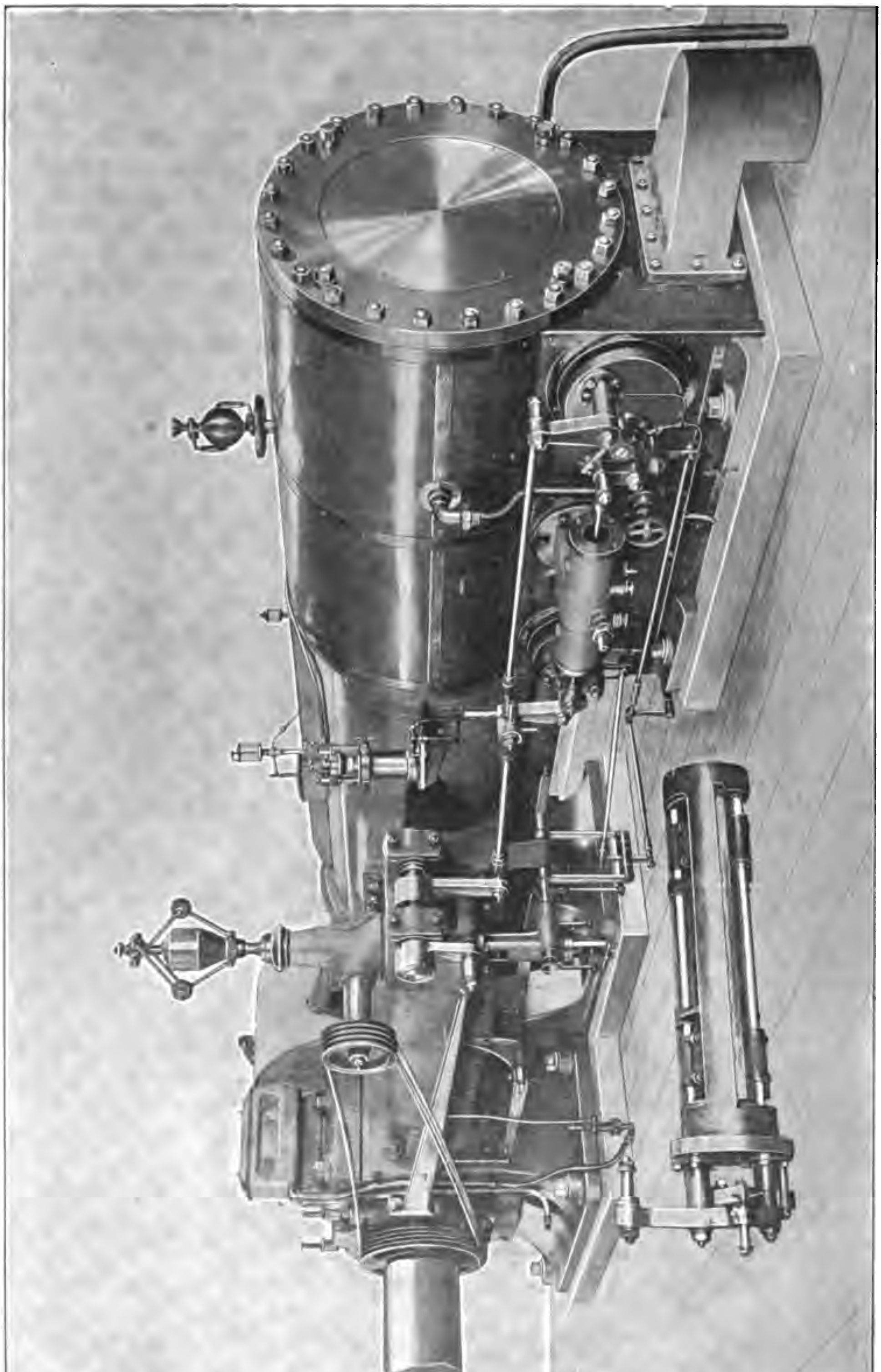
The ordinary run of contracting electrical engineering—beyond the large municipal, tramway, railway, and distribution in bulk systems, in which the larger powers are employed—consists of isolated plants in country houses, ships, mines, and large factories, where the units are very rarely over 200 K.W. The large plants are in the practice of only a few firms, who are not likely to consult works of this nature in regard to engines and dynamos; we shall therefore only briefly refer to plants over 200 K.W. output.

The smaller plants are often put in by contractors, who purchase the engines and dynamos separately or combined, and a good deal of profitable engineering business is carried on throughout the country and colonies in isolated plants of these smaller sizes.

For large, slow-speed horizontal compound engines, illustrations are shown of Adamson's Tandem Corliss gear engine. The horizontal engine, with automatic-expansion governor, has the advantage of easy access of parts, and has always a more cleanly appearance than the vertical engine, as grease and drippings fall away below the engine, and the parts — such as connecting-rod ends, valves, and grease cups—are more readily got at for attention than in the vertical engine. The vertical engine, however, takes up much less space on the floor, and if properly designed and balanced, requires much less foundation work; and probably some advantage also arises from the pistons of a vertical engine rubbing against the cylinders equally all round, without depending on the guiding power of the piston rods.

Messrs. Daniel Adamson's tandem compound horizontal engine is shown in Fig. 45, which gives a general view of a tandem compound engine of usual standard pattern, being fitted with trunk girder frame, the high and low-pressure cylinders being in line with each other. An important feature in the design is that the metal is

Tandem Compound Engine



Wheelock Gear and Valves

FIG. 45.—Tandem Horizontal Compound Engine

so disposed as to be as much as possible in the direct line of strain. The trunk principle of construction is adopted throughout; not only between the high-pressure cylinder and the main bearing, but also as a means of connecting the high and low-pressure cylinders together; the whole of the arrangement allowing the different parts being finished by machine tools, ensuring perfectly true alignment and mechanical accuracy throughout. The cylinders are fitted with Messrs. Adamson's patent Wheelock gear and valves. This valve gear is of the single eccentric type, and embodies principles of construction peculiar to the Wheelock patent. The valves, seats and valves are of the grid type, and are self-contained, being in the form of a plug (see illustration of valves attached to cylinder), the valve seat being quite independent of the cylinder casting itself. The plug forming the valve seat is driven into a suitable hole, bored a little tapering, on each end of the cylinder; no wear takes place in the cylinder, due to the action of the valves, which allows of spare valves and seats being kept in stock. The valves and seats, being of the flat grid type, give large area of opening with a minimum of movement. The reciprocating movement of the valves on the seats is effected by toggle joints and links, so arranged as to dwell or pause during the periods when the valves are closed, whilst, when opening, the speed is accelerated, thus ensuring quick opening and closing of the valves with a minimum of loss in initial pressure.

This system of automatic-expansion governor can be applied to any engine, and has considerable advantages for large engines. The plug system reduces the cost of overhauling, repairing, and adjusting those vital parts of the engine engaged in governing and steam distribution.

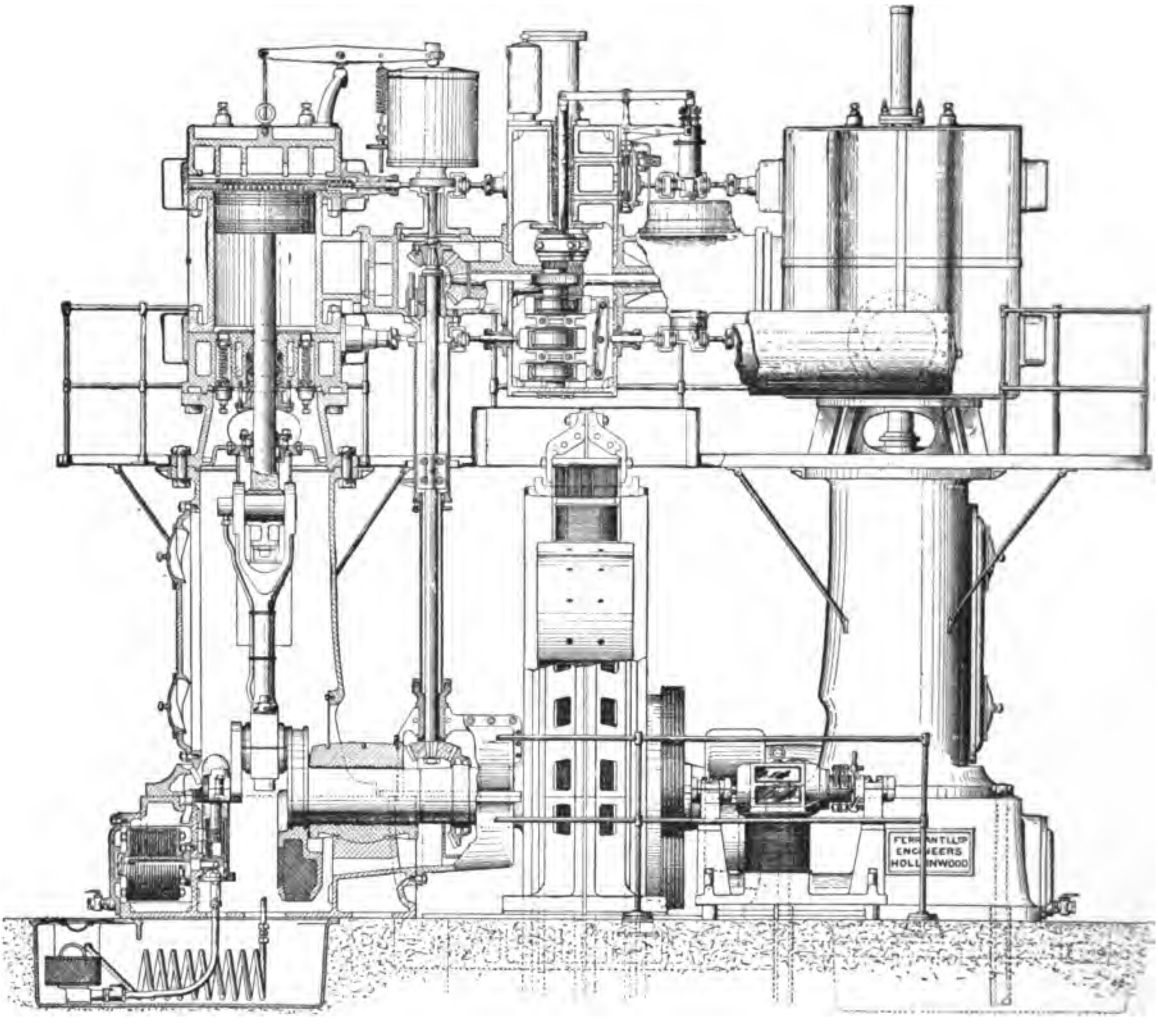
Mr. Ferranti was among the first to adopt direct-connected large engines and dynamos, and he has introduced a vertical type of engine, which is shown partly in section in Fig. 46, with the dynamo between the two engines. It is a fairly high-speed engine for its size, but the design has been worked out with this well in view.

All parts of the engine are thoroughly enclosed, and a complete system of forced lubrication applied to all moving parts. By this means thorough reliability of working is secured, as the engine lubricates automatically, avoiding the element of danger involved through the carelessness of a driver, and reducing the cost of oil to a minimum.

The subject of floor space receives special consideration, and it is established that the floor space occupied by this engine is the smallest of any on the market. This, of course, has in cities a very important bearing on the capital expenditure for land and buildings.

On account of the varying loads in electrical work, it is of great

importance to secure a good steam consumption, not only at full load, but through a range of at least half the output of the engine. The valve gear is designed with a view to achieving the best results in this direction, and the results achieved by this plant have given the greatest satisfaction in this respect. The standard engine for



Oil Pump. FIG. 46.—Elevation of Ferranti Engine, one half shown in Section

all sizes up to 2500 horse-power is of the cross compound type. Each cylinder is fitted with two steam and two exhaust valves, in order to secure the greatest economy. These valves are positively driven by cams so arranged that the steam valves give a quick cut-off, thus achieving the same result that, on Corliss engines, is got by introducing the complication of trip gear.

The valves themselves are placed immediately above and below the piston, thus securing the economic advantages of a small steam clearance.

The engines have been made up to 3000 K.W. output, principally for electric-tramway work.

There has been a good deal of difference of opinion expressed regarding the placing of the generators between the engines instead of at one or both ends, some engineers preferring the engines as compact as possible, with the dynamos outside; and this is the general arrangement with high-speed engines. Experience alone can decide this question.

It is claimed by the advocates of these large, slow-speed engines that, when large powers like two or three thousand horse-power and over are necessary, the slow-speed is much less expensive in maintenance and repair; and from all accounts that contention is pretty well supported by experience.

My own opinion on the matter is that we will finally arrive at a common practice, in which large, slow-revolution engines or steam-turbines will be used to a much greater extent, in place of the quick-revolution steam-engine reciprocating in motion.

At present, however, by far the most electric-generating plants are composed of quick-revolution engines and dynamos. Among the first of these to be introduced was the Willans engine, so common in nearly every municipal plant for continuous current.

It may be here remarked that the continuous-current engineers have adhered most tenaciously to the quick-revolution engine, while the alternating-current engineers have preferred the slow-speed engine, using the fly-wheel as the field magnets. The difference is due to the fact that the heavy part can be rotated—that is, the field magnets of an alternator—while the armature may be a fixture; on the other hand, a continuous-current generator must have the armature rotating, so that the fly-wheel is needed extra, the armature not being heavy enough for the fly-wheel effect required.

A sectional view of a two-crank Willans engine is shown in Fig. 47. The steam is distributed throughout by the hollow piston-rod (sometimes called the "trunk"). It enters from the steam chest by the cut-off ports (1), shown near the top of the piston-rod. By the movement of the line of piston valves, which work inside the piston-rod (driven by the eccentric shown), the steam passes into the H.P. cylinder, at the beginning of the stroke, by the holes or ports (2) shown just above the H.P. piston. It is important to remember that this ring of ports is the only inlet to and outlet from the cylinder, and that it moves up and down with the piston. The action of the valve inside is shown in detail in the left-hand line of cylinders, where it is represented in the admission position.

The valve gives just the same steam distribution as an ordinary

slide valve, with a slow cut-off at about three-quarter stroke, or a

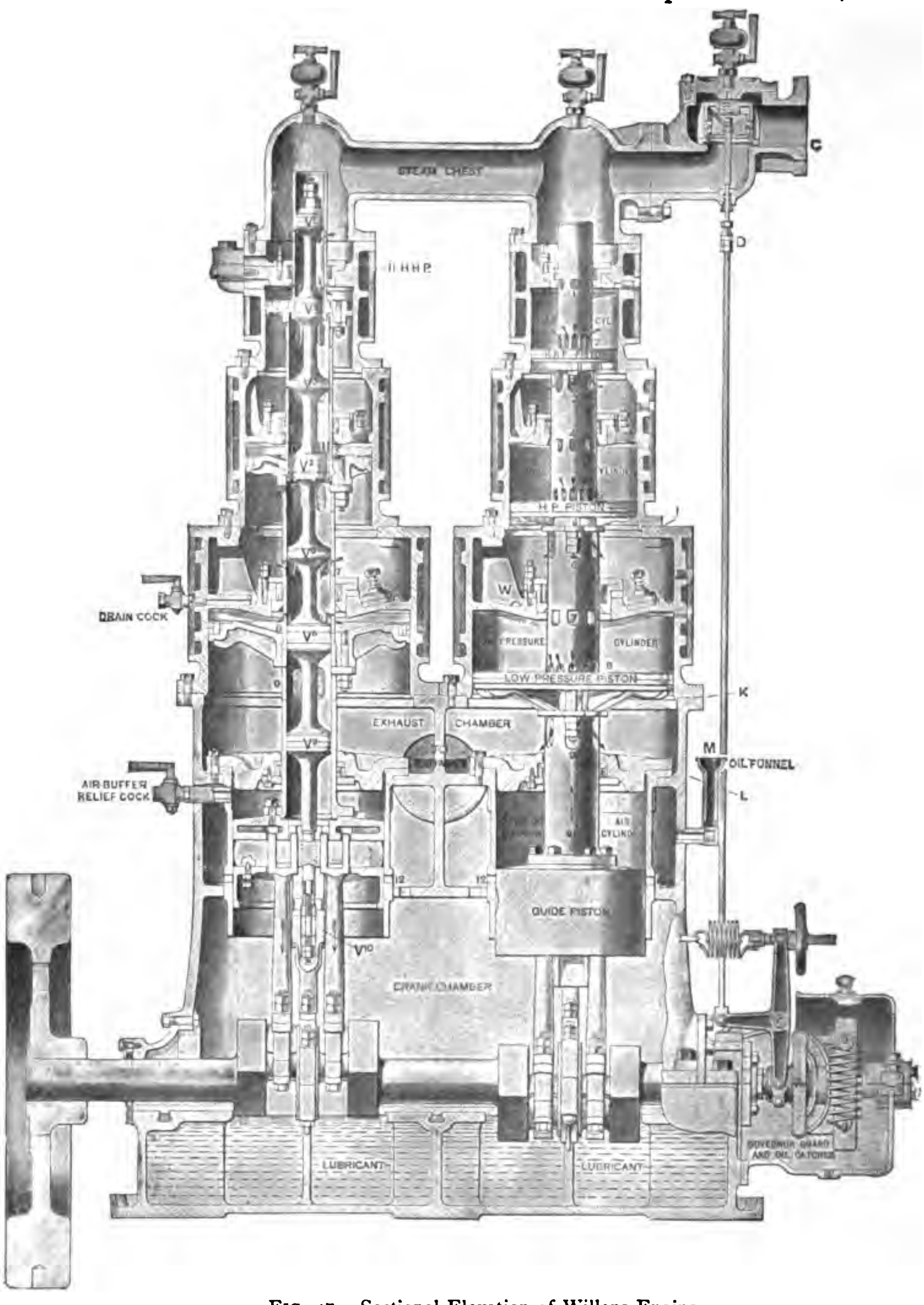


FIG. 47.—Sectional Elevation of Willans Engine

little later. The actual cut-off is, however, effected by the upper

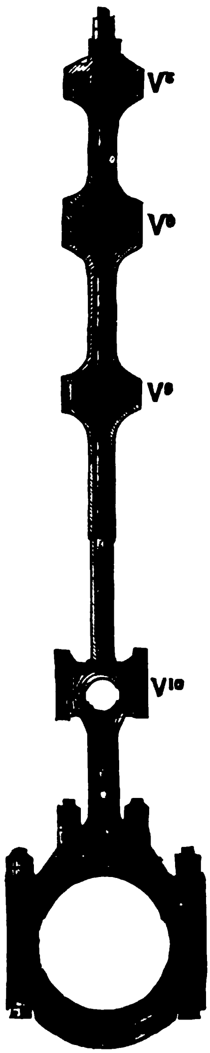
ports (1) in the trunk, which, at a point in the stroke either pre-arranged in the design of the engine, or controlled by the governor, pass down through a gland (ring packed) into the cylinder, and so leave the steam chest, thus preventing the further supply of steam for that revolution. As the cut-off movement corresponds with that of the pistons themselves, the cut-off is very prompt, and shows a sharp corner in the diagram.

After the steam has worked expansively in the H.P. cylinder, the valve passes above the ports (2) and opens communication from the working end of the cylinder—*i.e.* the space above the piston—to the space below it, which is called the first receiver, but which is equally a steam chest for the I.P. or intermediate cylinder. During the up-stroke, the steam is simply transferred from one side of the piston to the other; the whole cylinder, including the "working end," at that time forms part of the receiver.

When the next down-stroke commences, the steam in the first receiver is passed into the I.P. cylinder. It enters the hollow piston-rod again from the receiver by the ring of short square-headed holes (4) shown, and passes from the piston-rod to the cylinder by the ring of ports (5) shown, just above the I.P. piston. Cut-off in this case is given by the square-headed ports (4) passing into the gland in the I.P. cylinder cover, and so losing the supply of steam from the receiver. The course followed by the steam is exactly the same as already described for the H.P. cylinder, and, at the end of the *second* revolution, the steam fills the second receiver. Thence, in the *third* revolution, it passes into the L.P. cylinder; and in the second, or exhaust, half of that revolution, it passes from the L.P. cylinder to the condenser.

The arrangements for self-drainage from the cylinders are of great importance in the economy of the engine, as the exhaust ports are so placed that the rush of steam carries out the water with it, not only at the moment of opening the port, but continuously through the *whole* of the up-stroke, this action being assisted by the dished form of the patent pistons employed. The action is thus radically different from that of other forms of vertical engines, in which the water is retained in the cylinder

FOR SIMPLE ENGINE



DETAILS OF VALVES AND ECCENTRIC ROD

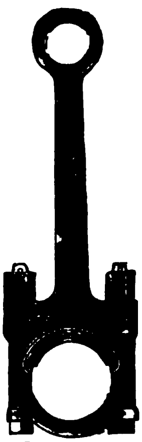
FIG. 48

during the whole of the return stroke, and then driven suddenly through the port.

In a compound engine there are but two cylinders in series, but the steam distribution in each is precisely the same; in a simple engine there is only one cylinder over each crank.

The line of valves is driven by an eccentric *on the crank-pin.* It is necessary that the source of motion for the valves should itself move up and down with the pistons, since the ports which have to be opened and closed also move up and down. There is an eccentric rod which takes on to a hardened pin in a valve guide-piston; the latter works in a bored guide formed inside the main guide-piston.

There are two connecting rods to each line of pistons, one on each side of the eccentric; the eccentric rod plays between them.



DETAILS OF CONNECTING ROD

FIG. 49

The cranks and all the working parts, except the cylinders and valves, are lubricated by the splash of the cranks in the crank-chamber, where the lubricant usually consists of a mixture of oil and water. The guides and the pins at the upper ends of the connecting rods and eccentric rods are equally reached by the splash.

The cut-off in the first or H.P. cylinder is effected, as before stated, by the movement of the ports in that part of the hollow piston-rod which projects into the steam chest. Where the engine has an invariable expansion, the cut-off ports, as they are called, are of the same shape as those for the succeeding cylinders, and they lose their supply of steam by merely passing into the gland which separates the H.P. cylinder from the steam chest. If early cut-off is desired, the gland itself is raised a little by packing pieces between it and the cylinder top. In that case the ports enter the gland earlier, and cut-off is earlier.

Where the expansion is to be made variable, either by hand or by the governor, inclined ports are used, and the upper end of the piston-rod is surrounded by a sleeve, which also has inclined ports in it. The sleeve is capable of a certain amount of rotation, which causes the ports in the rod to be covered (by the solid part of the sleeve) earlier or later. The sleeve is suspended by a spindle which passes through a gland in the top of the steam chest, and the spindle is rotated by suitable links, &c. These are moved by hand, or by a relay cylinder, the action of which is controlled by the governor.

Fig. 50 shows one of the sets in Edinburgh municipal central station, coupled to a Mather & Platt dynamo.

Fig. 48 illustrates the valves and eccentric strap of the simple

engine, Fig. 49 the connecting rod, and Fig. 51 the lubricant

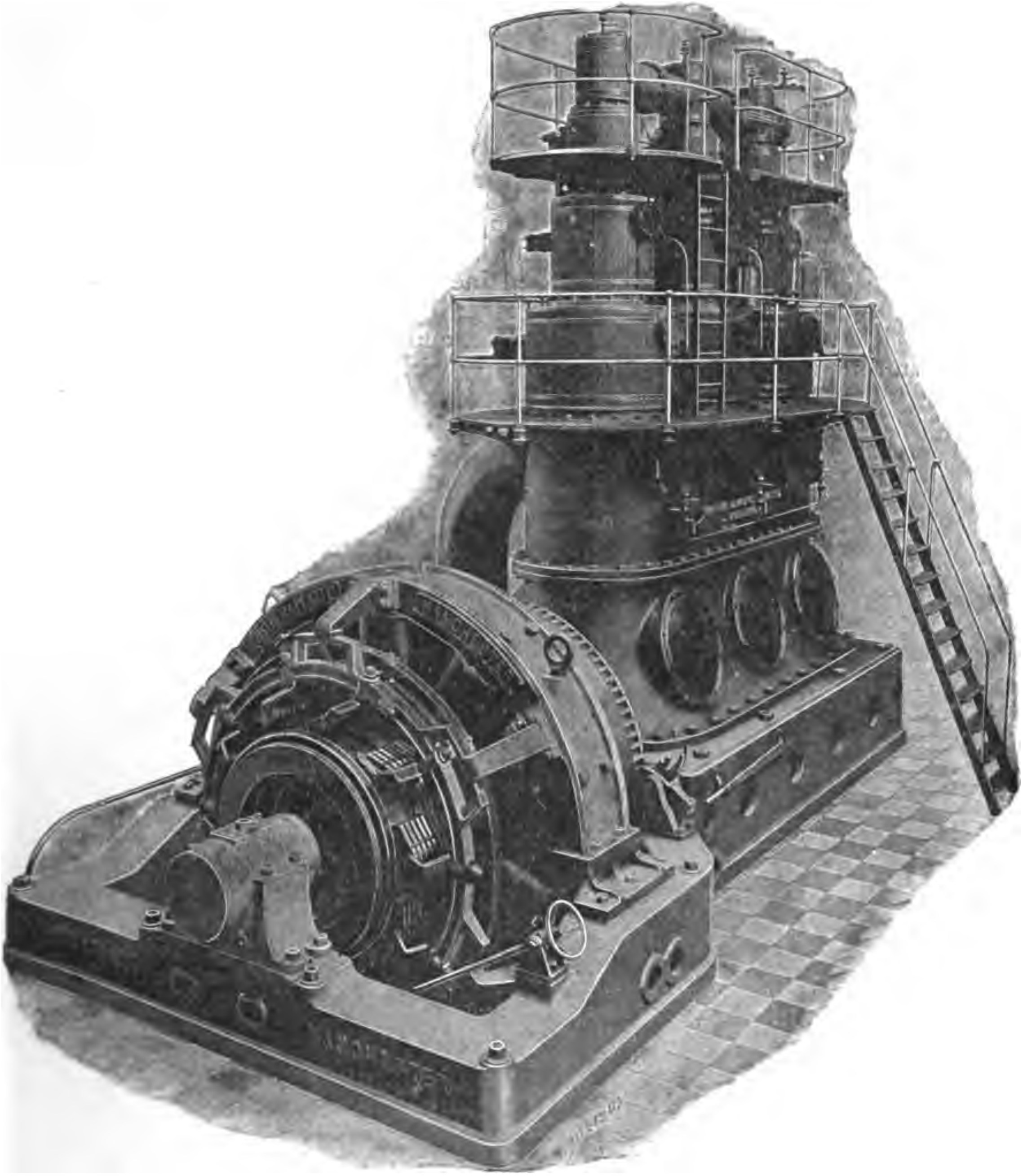


FIG. 50.—Willans Engine and Mather & Platt Generator

gauge, in which the part X acts as an air-vessel to prevent

violent oscillations of the surface at Y. The engine is governed by a throttle valve, operated by an adjustable centrifugal governor.

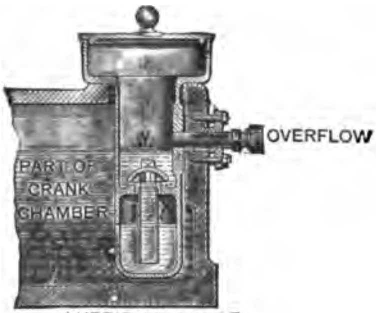


FIG. 51

Another single-acting engine which has met with considerable success is the Westinghouse compound engine, shown in section in Fig. 53.

Long before any other engineers, Westinghouse advocated the economy of compounding, even where condensing could not be employed, and this engine was designed to prove the contention.

I have already referred to the great number and cost of auxiliary plant required to obtain high efficiency with reciprocating and other

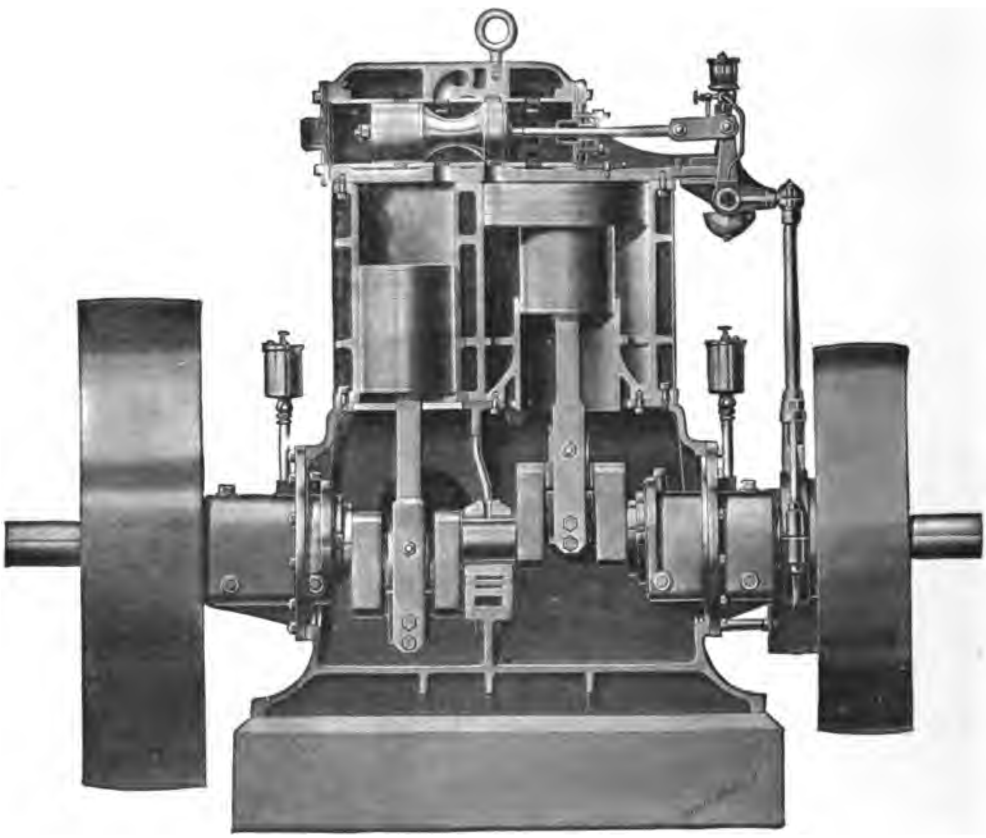


FIG. 52.—Sectional Elevation of Westinghouse Compound Engine

steam-engines. As to efficiencies in general, the common ideas are obtained from special results of tests carefully prepared and at fixed load.

Economy of Compounding

Actual practical tests are difficult to carry out, for, to get anything like reliable data, it is necessary to run the engines at various loads, and to carefully measure coal and water consumed in one boiler; which boiler not only drives the engine under test, but also works the whole auxiliary plant during the tests. And again, in estimating the cost of producing one electrical unit, the cost of the plant employed to produce it, both in maintenance and first cost, must be taken into account.

The man of business is interested in the production of power at the least possible expense per unit of output, and will realise that the bare steam used by the engine is only one of the items which enter into the cost of power, and that a saving of twenty shillings in this item is dearly bought if it necessitates an expenditure of twenty-five shillings in other directions.

The normal steam consumption of a Westinghouse compound engine of moderate size, condensing and non-condensing, under varying conditions of load and steam pressure, is shown in the accompanying table, which is the average and summation of a large number of tests made over a continuous period of several months. This table was compiled thirteen years ago, and its accuracy has been verified by tests made since that time.

The engine is certainly simple, and proves that, within practical limits to the load, condensing is not necessary in every case with compound engines, and that compounding is an advantage in all engines.

TABLE OF ACTUAL STEAM CONSUMED PER INDICATED HORSE-POWER: CYLINDERS 14″ AND 24″ × 14″ UNDER VARYING LOADS AND PRESSURES.

Unjacketed and Uncorrected for Entrained Water.

Non-Condensing.					Condensing.			
Boiler Pressures.				Horse Powers.	Boiler Pressures.			
60 lbs.	80 lbs.	100 lbs.	120 lbs.		120 lbs.	100 lbs.	80 lbs.	60 lbs.
			22.6	210	18.4			
		23.0	21.9	170	18.1	18.8		
	24.9	23.6	22.2	140	18.2	18.5	20.0	
	25.7	23.9	22.2	115	18.2	18.6	19.6	20.5
26.9	25.2	24.9	22.4	100	18.3	18.6	19.7	20.3
27.7	25.2	25.1	24.6	80	18.3	18.6	19.9	20.1
30.3	28.7	29.4	28.8	50	20.4	20.8	20.7	20.4

As indicated by the sectional view, Fig. 52, the engine consists in general of a pair of vertical cylinders bolted to the top of the crank

case, the latter serving the double purpose of a rigid pedestal for the engine and a receptacle for the lubricating material. The steam chest is bolted horizontally across the top of the cylinders, motion to the valve being communicated through a bell crank from the governor on one end of the shaft. A driving pulley of suitable size is carried on the opposite end of the shaft. The crank base is filled with water to such a height as to half submerge the crank pin at the bottom of its throw, and on this water is floated about one half-inch of heavy black oil. Fig. 53 shows in greater detail the valves and pistons in section.

S and E are the steam and exhaust chambers around the bushing, into which connect respectively the steam and exhaust

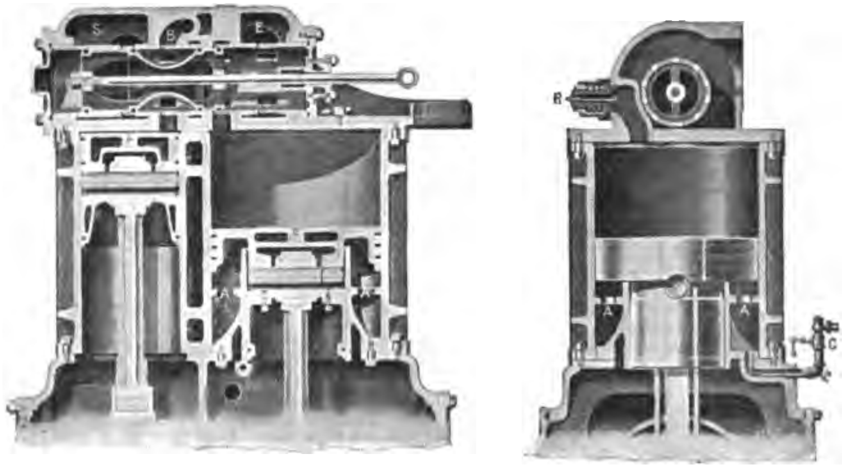


FIG. 53.—Detail of Cylinders, Pistons, Steam Chest, and Valve of Westinghouse Compound Engine

pipes. The curved passage B connects, through the by-pass valve, controlled by a hand wheel on the back of the steam chest, with the steam space S. The purpose of this by-pass is fully explained in the description of the steam distribution.

By the construction adopted, the displacement of each piston is made the same, and the volume of air in the crank case remains practically constant. The annular space A underneath the larger diameter of the piston and outside of the sleeve forms a cushion chamber, in which the inclosed air is slightly compressed at the bottom of the stroke, and a partial vacuum formed at the top of the stroke. This action, involving no loss of power, assists in absorbing the momentum of the larger piston at the end of the stroke, and materially relieves the crank pin and connecting rod of that duty. This cushion space is drained by a spring check valve, C, shown in section in marginal cut. By means of the handle, the valve can be

held off its seat to destroy the cushioning action when starting or turning the engine over by hand.

The connecting rod, shown in detail in Fig. 54, consists of a continuous forged strap A, extending the entire length of each side and around the top, and machined on the inside to receive the boxes C, D, E, and F. The box D is secured by dowel pins, and the box E is firmly held in place by two heavy bolts. The boxes C and F are a sliding fit in the strap, and held sidewise by projecting flanges. B is a forged steel strut or distance piece, with square ends fitted to the inner surfaces of the strap. At the upper end the strut B bears against the bottom of the box C, while the lower end bears against the flat side of a wedge interposed between it and the inclined upper side of the box F. Owing to the single-acting principle involved, the boxes D and E merely act as keepers, all wear coming on C and F. By drawing up the wedge with its bolt, readily accessible through the opening in the crank case, the box F is forced downward, and through the strut B the box C is forced upward, thus

FIG. 54.—Connecting Rod for Westinghouse Compound Engine

taking up the lost motion at both ends simultaneously and equally with a single adjusting screw. When the boxes are worn sufficiently to allow the wedge to go to its extreme travel, it is set back again, and one or more sheet steel plates or "shims" placed between it and the end of the strut to compensate for the wear.

Boxes C and D are solid phosphor bronze; for the crank pin boxes E and F, with the lighter pressures per square inch of surface and higher-surface velocities, we have found nothing so suitable as a lining of genuine babbitt. F has deep flanges extending upward on the sides—broken away in the section—covering the wedge, and acting as a sidewise retainer for B. The upper end of B is also held by shallow flanges on C.

The same kind of rods might with advantage be used in the gas-engine for ready adjustment.

The governors for these engines are worthy of extended notice, for they are typical of all fly-wheel governors. With small modifications, nearly every engine-maker makes a fly-wheel governor.

The governor shown in Fig. 55 is of the at present popular "single weight" or "inertia" type, built with minor modifications

by a dozen or more manufacturers. The adoption of this form of governor is no apology for the original double-weight enclosed type, running in oil, which always was and always will be a most efficient and reliable piece of mechanism. The new design, however, has the features of greater simplicity and accessibility, and is capable of giving that ultra close regulation which is just now a somewhat popular fad. It is possible to adjust this governor so that there is no apparent difference in speed whether the engine be running empty or fully loaded, and it is even possible to adjust it so that the speed with the engine fully loaded is one or two per cent. greater than when running empty. This sort of regulation is of no commercial value. Perfect steadiness is the first requisite of a good governor,

Front View Rear View

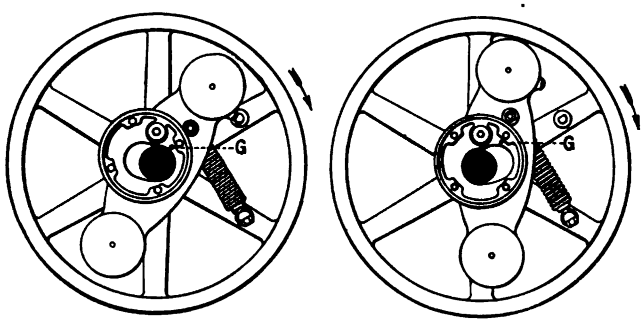
FIG. 55.—The Inertia Governor of Westinghouse Compound Engine

and a slight falling off in speed with increase of load contributes to that quality.

In general, the inertia governor consists of a single weight of the typical form shown in Fig. 56, pivoted on the hub of the governor wheel to one side of the shaft, the centre of gravity of the weight being located approximately at G. A spring, with an adjusting screw to regulate the tension, is attached to the wheel and the weight at convenient points. Rotation being in the direction of the arrow, any increase in speed tends to make the centre of gravity of the weight seek a position farther away from the centre of the shaft, and causes the weight to swing on its pivot in a direction opposite to that of the wheel. The eccentric is attached to the weight, and this movement brings the centre of the eccentric nearer the centre of the shaft and increases its angular advance, thus effecting an earlier cut-off. Fig. 56 shows the position of the governor at longest travel and cut-off, and at shortest or zero cut-off, where the valve travel is just equal to the lap. The greater part of the weight lying outside the pivot, if there be any sudden

tendency of the engine to increase its speed, the weight by its inertia tends to lag behind the wheel, thus augmenting or almost anticipating the effect of centrifugal force, and bringing the eccentric to a shorter cut-off. Conversely, if load be suddenly thrown on the engine, and there be a consequent tendency to drop in speed, the weight by its own inertia tends to rotate at the same speed and runs a little ahead of the wheel, swinging the eccentric to a position of longer cut-off. It will thus be seen that in this type of governor, when properly designed, centrifugal force, the primary regulating force, is aided by the inertia of the weight, and the action of the governor is thereby materially hastened.

The steam distribution in the Westinghouse compound engine is particularly novel and interesting, being effected by a single valve instead of from two to eight, as ordinarily used. The principles of



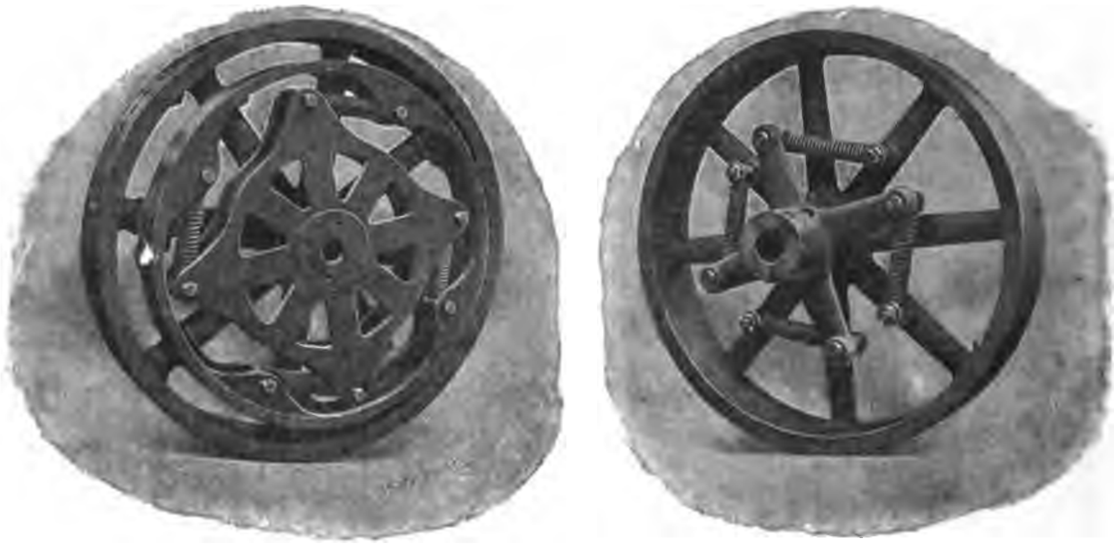
At Longest Cut-off At Shortest Cut-off

FIG. 56.—Position of Inertia Governor Parts at Longest and Shortest Cut-off

compounding are now so generally understood that we need only make passing mention of them. The greatest loss in the steam-engine is that due to internal condensation, and the object of compounding is to reduce this loss. As steam enters the cylinder of an engine, it first heats up the cylinder walls to its own temperature, and a certain amount is condensed thereby. As the steam expands after cut-off, its temperature drops, and, if expansion be carried out to any reasonable extent by the time the exhaust opens, the cylinder is many degrees hotter than the steam. Heat then naturally passes from the walls of the cylinder to the steam during exhaust, re-evaporating the water formed by condensation during admission, reducing the temperature of the cylinder walls, and necessitating the condensation of a portion of the next incoming steam. In short, a portion of the steam admitted is instantly condensed before it can do any work, and is re-evaporated after it is too late to do any work, and is wasted through the exhaust.

The higher the initial pressure, and the lower the exhaust tem-

perature, the greater this loss becomes. For any given initial and exhaust pressures, it is practically a constant quantity, and therefore with increasing ratios of expansion it becomes a larger percentage of the steam admitted, so that in the simple engine with a very limited number of expansions the loss from this source begins to overbalance the gain from further expansion. In the compound engine, we divide the range of temperature from admission to exhaust between two cylinders; consequently, the maximum difference of temperature that can exist at any time between the cylinder and the steam is very much less, and the quantity of heat that can be usefully transferred is correspondingly reduced. Furthermore, the condensation of the high-pressure cylinder is not wholly loss, as the



Styles A and B Style C

FIG. 57.—Westinghouse Flexible Coupling

steam formed by re-evaporation is not wasted, but passes into the low-pressure cylinder, where it does work, or in a measure compensates for the losses in that cylinder.

The by-pass valve B, as previously stated, is merely a convenience for starting. If the engine is standing with its high-pressure piston at the top of its stroke, it can be started without. On completing half the revolution, the valve will have cut-off communication between the low-pressure cylinder and the space around the neck of the valve, as shown in Fig. 53, leaving the pressure on the high-pressure piston only, which will consequently descend and complete the revolution. This is the only office of the by-pass valve, and it should be closed as soon as the engine is fairly under way, and before the throttle valve is fully opened.

The engine and dynamo are mounted on a heavy, continuous bed plate, and connected by a flexible spring coupling. Different forms of this coupling are shown in Fig. 57. The wheel is keyed on the engine shaft and acts as a fly-wheel, while the other part or "spider" is attached to the dynamo shaft—either keyed on or bolted to a flange. The only connection between the wheel and the spider is through the spiral springs shown, one end of each spring being attached to the wheel, and the other end to the spider.

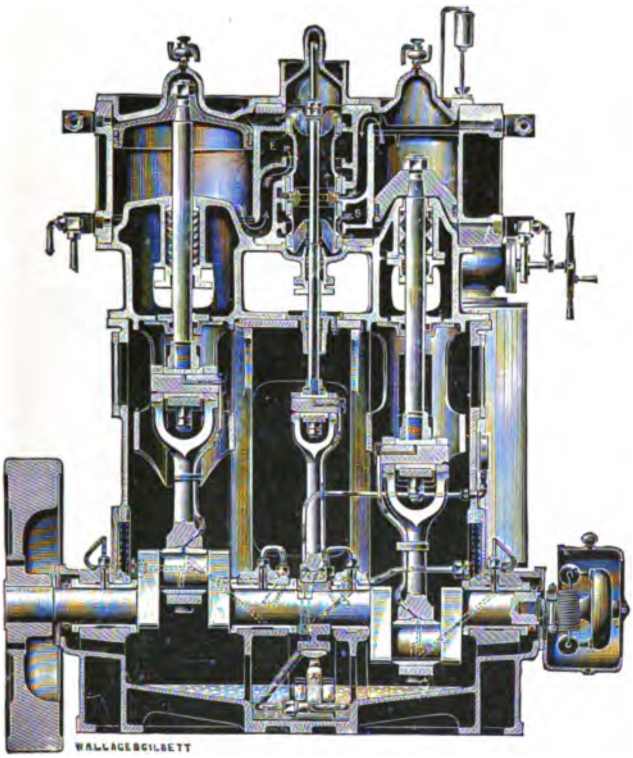


FIG. 58.—Sectional Elevation of Belliss & Morcom Engine

Styles A and B are identical in appearance, the only difference between them being that in style A the wheel and spider are electrically insulated from each other. When the insulated coupling is used, the frame of the generator is also completely insulated from the bed plate. Style C is perhaps less attractive, considered solely as a piece of machine design, but is equally efficient.

The spring coupling has several points of merit. By its use the question of the perfect alignment of bearings is eliminated, contributing to cool running, and making the effect of unequal wear in engine bearings and dynamo bearings negligible. The cushioning effect of the spring transmission, in absorbing shocks due to sudden

changes of load or to accidental short circuits, must of necessity be beneficial to both engine and generator.

There exists, however, partially on account of greater compactness, partially because of the difference in cost between a complete dynamo and a simple armature and field frame without shaft or bearings, a preference for a construction involving an extension of the engine shaft, carrying the armature, and supported by a single

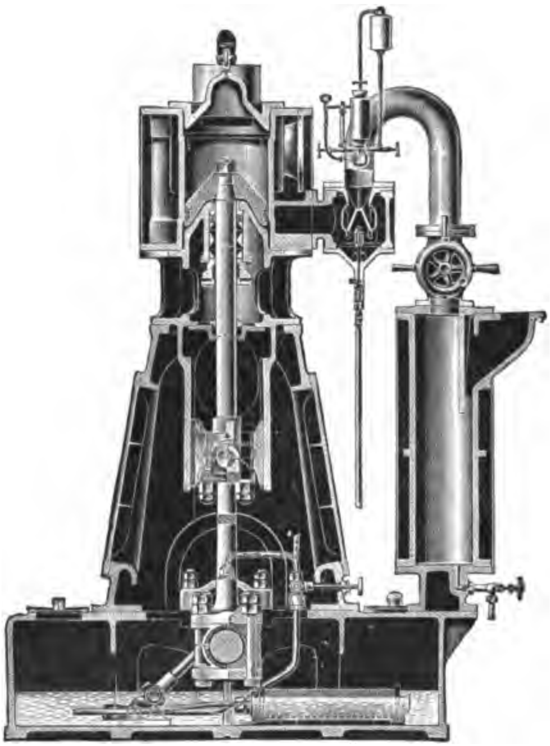


FIG. 59.—Cross Section of Belliss & Morcom Engine

bearing at the outer end, as shown in most combined plants illustrated, see Fig. 76.

We have given these details of this engine more attention on account of the simplicity of the whole engine, the full illustrations enabling the student to gather clear ideas, and so that we need not go into the questions again when describing other engines.

We now come to consider the large class of high-speed double-acting vertical engines. They are of two types, open and enclosed.

The Belliss & Morcom engine has been largely employed, Fig. 59.

This firm introduced forced lubrication some twelve years ago. The oil is supplied to all the principal bearings by a pump at a

pressure of 10 to 20 lbs. The used oil collects in the crank chamber, and is withdrawn and filtered to be used again.

As shown in the sections of the engine, Figs. 58 and 59, the cranks and rods are enclosed in a casing, the cylinders with their packing glands being outside. The governor shown is a centrifugal throttle. The makers undertake to produce 1 horse-power on a

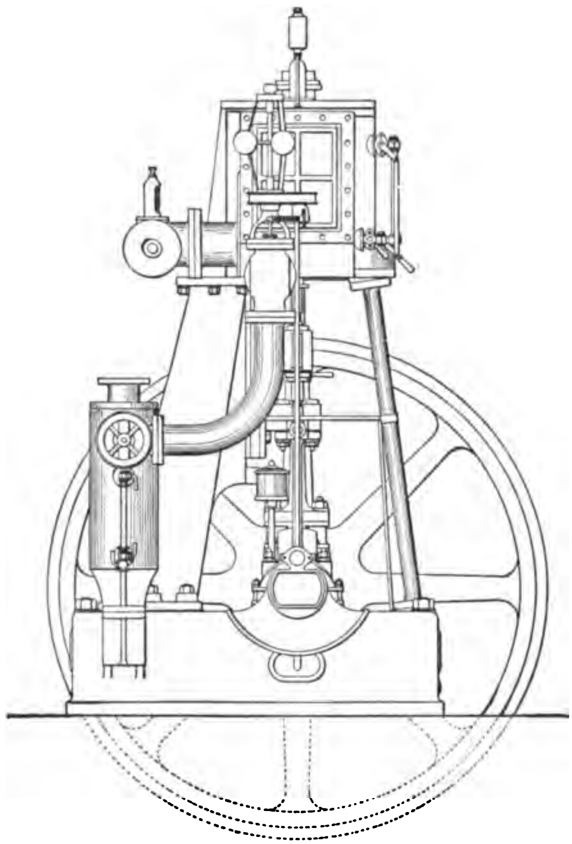


FIG. 60.—End View of Mather & Platt Engine

consumption of 14 lbs. per hour of steam in the engine, or 19 lbs. per K.W.

The general design is common to many makers of compound and triple expansion engines. It is impossible to describe them all in the space allowed, and not necessary. The selections made are not preferred for any other purpose than merely to well illustrate the best practice carried on by many firms besides those whose engines are shown and described.

Many engineers prefer the open type of vertical marine engine. Among these makers are Messrs. J. H. M'Laren, Leeds; Mather and Platt, Manchester; Robey & Co., and many others.

Open Vertical Compound Engine

This type is well illustrated by the two views of Messrs. Mather and Platt's engine, Figs. 60, 61 ; speed is 250 revolutions per minute.

Messrs. Robey & Co. make an automatic expansion trip gear, which may be taken as an example to explain many others. It is shown in Fig. 62.

A is the admission valve, and, being almost in equilibrium, is lifted with great ease by the small eccentric and rods worked from a shaft revolving at the same speed as the engine, and parallel with the bed plate.

The admission valve is raised at the commencement of the stroke, and held wide open until the point of cut-off is reached, when it is

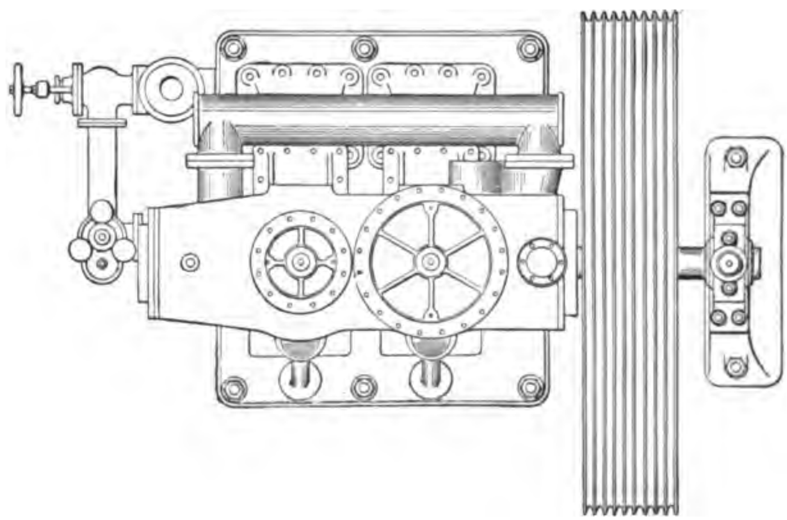


FIG. 61.—Plan of Mather & Platt Engine

instantly relieved, and falls on its seat, an air cushion in the guide cylinder above preventing its falling too heavily.

While the valves are alternately raised by the engine, the point at which they are dropped depends upon the position of the governor, which regulates the cut-off at any point from nothing to $\frac{5}{8}$ of the stroke.

At the bottom of the cylinder are the exhaust valves. These are triple ported so as to give wide opening with a small travel, and work with a minimum of friction. Being placed directly under the cylinder, this latter is kept perfectly drained, and both admission and exhaust valve being close to cylinder body, the loss of steam in ports is avoided.

Referring to the cross section of the cylinder, which shows very clearly the whole of the gear for one end of the cylinder, it will be seen that the small eccentric rod K is enabled to act upon the

valve A (which is in equilibrium) by depressing the outer end of the lever B, by which the valve is raised.

This occurs just before the commencement of the stroke.

Owing to the different arcs described by the end of the eccentric rod and the lever B respectively, at a certain point the tripper L slips out of contact, and the valve drops instantaneously, cutting off the steam supply.

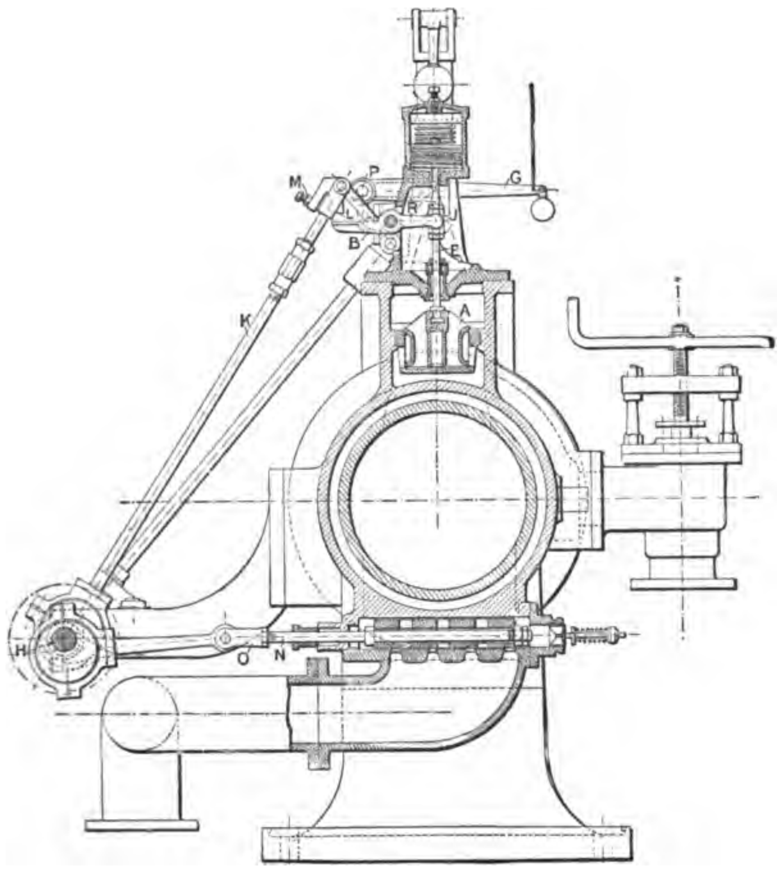


FIG. 62

The arrangement for securing an automatic cut-off is simplicity itself, the governor in rising moves the lever arm, and with it the pivot or fulcrum R of lever B, which of course has the effect of causing the tripper L to lose its contact and the valve to fall at an earlier period in the stroke, and thus, as the governor rises and falls, the point of cut-off is accelerated or retarded accordingly.

It will be noticed that the long horizontal arm of lever is prolonged past the governor, and that a small cord or string is attached

to it. This cord may be led away to any part of the building, and forms a ready means of instantly stopping the engine in case of emergency, as in the case of accident to life or machinery. By pulling the cord, which is done with no more exertion than is required to ring an ordinary house bell, the lever G draws the valve levers B completely clear of the trippers, when, of course, no steam can enter the cylinders, and the engine, which may have been exerting a thousand horse-power, may be brought to a stand at once by the touch of a child.

FIG. 63.—Ransomes, Sims & Jeffries' Shaft Governor

With so sensitive an apparatus as this, accurate governing is easy of attainment, and a small and simple centrifugal governor fulfils every requirement.

Messrs. Ransomes, Sims and Jeffries' shaft governor is here illustrated, Fig. 63, forming a neat enclosed and compact apparatus.

The shaft governor consists of a circular casting, keyed on the shaft, and carrying on one side a pair of symmetrically arranged weights, each of which is jointed to the casting at one end, while being free at the other end to move in a plane vertical to the shaft. On the other side of the circular casting are affixed a pair of straps, forming a circular recess, the centre of which is at a distance from that of the shaft. A disc is fitted into this recess, and on this disc, with its centre at a distance from the centre of the disc, is the eccentric which operates the slide valve. The weights are made with bosses, which pass through holes in the circular casting, and are connected by links to studs on the disc. The weights, in moving outwards by the action of centrifugal force, compress spiral springs, and at the same time rotate the disc in its recess, thus changing the position of the centre of the eccentric so as to vary the cut-off of the valve.

The condensing plant is the most important auxiliary to the steam-engine, but it is doubtful if condensing is to be recommended where water is scarce and requires to be artificially cooled, especially for plants under two or three hundred horse-power. For large plants it may and generally is found advantageous to condense, and use cooling towers to provide a continuous supply of cold water.

Steam Condensers

The simplest form is one used in Yorkshire mills, consisting of an elevated wooden rack of open woodwork, with a mass of brushwood filled in. The delivery from the condenser is

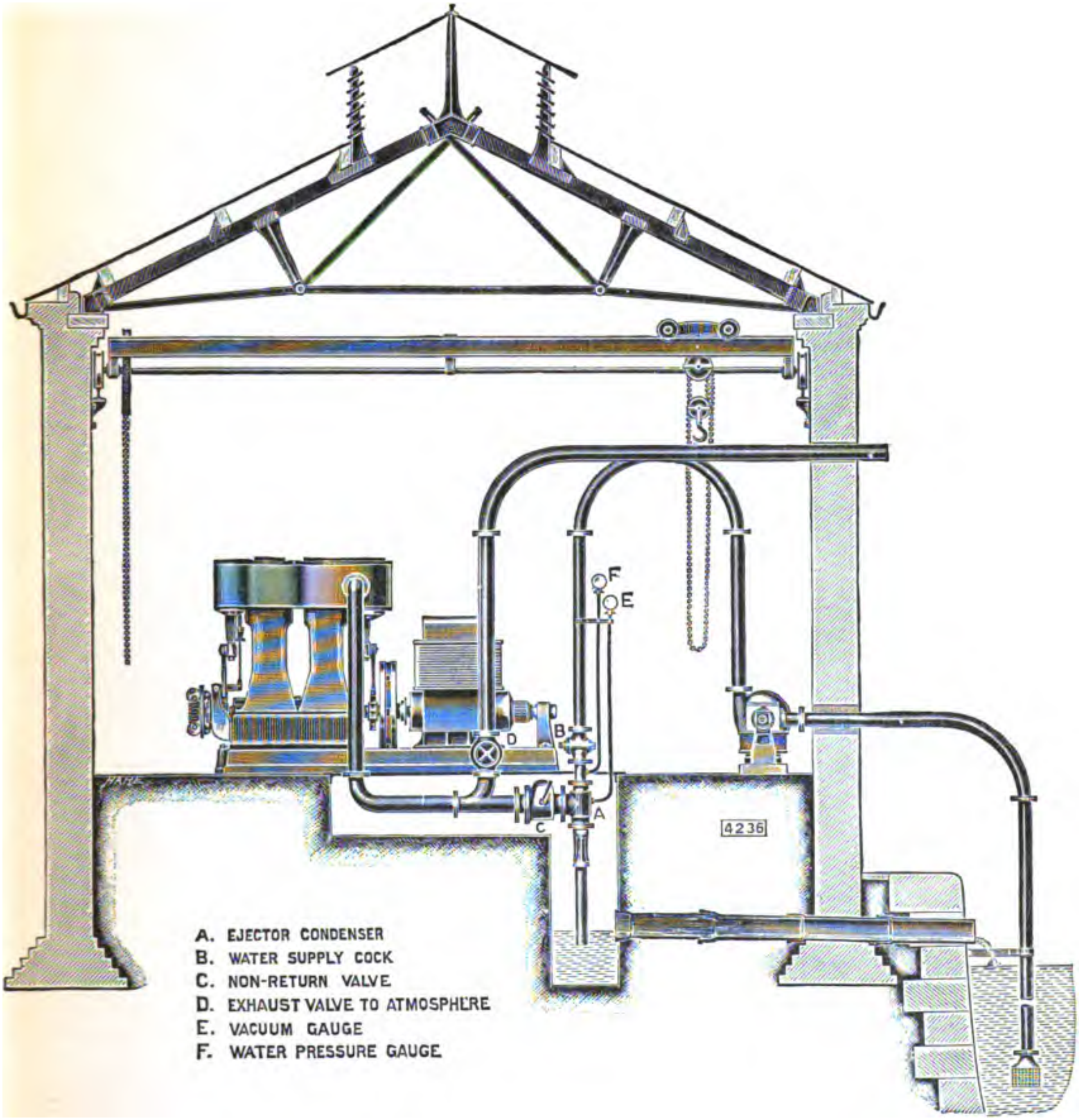


FIG. 64.—General Arrangement of Generating Plant with Jet Condensers

pumped up to the top, and allowed to trickle down through the brushwood into a small reservoir; the air, acting on the drops of water, cools them in two ways—first by contact and connection, and also by evaporation.

This same principle is used in cooling towers filled with tiles, and air drawn up through them by a fan-blower.

There are three types of condensers—surface condensers, jet condensers, and ejector condensers. The first two require an air pump; the third requires no air pump, but requires a fall of water.

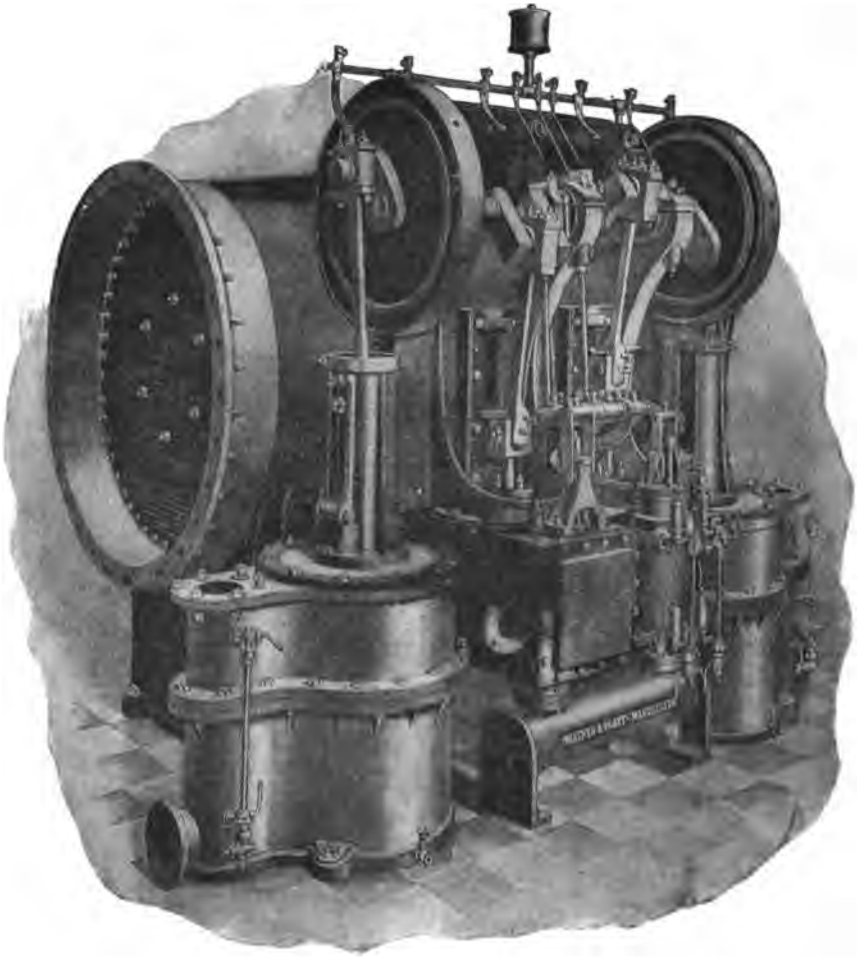


FIG. 65.—Surface Condenser and Air Pump, 1800 H.-P.

This is usually provided by pumping up the water into a tank, either by the engine or by an electric motor, as shown in diagram, Fig. 64. Where the ejector is fixed on the steam chest of the engine, and a centrifugal pump lifts the water, the supply tank should always be placed as directly above and as near to the condenser as possible; the distance between the bottom of the supply tank and the condenser inlet flange must not be less than 15 feet, and the length of

the vertical discharge pipe must not be less than 4 feet. The end of the vertical discharge pipe must be sealed by at least 2 inches of water, and there must be sufficient space between the end of the pipe and the bottom of the discharge tank to ensure the free outflow of the condensed and condensing water.

The vertical suction pipe should not exceed 12 feet in height.

For large plants separate condensers and air pumps are used,

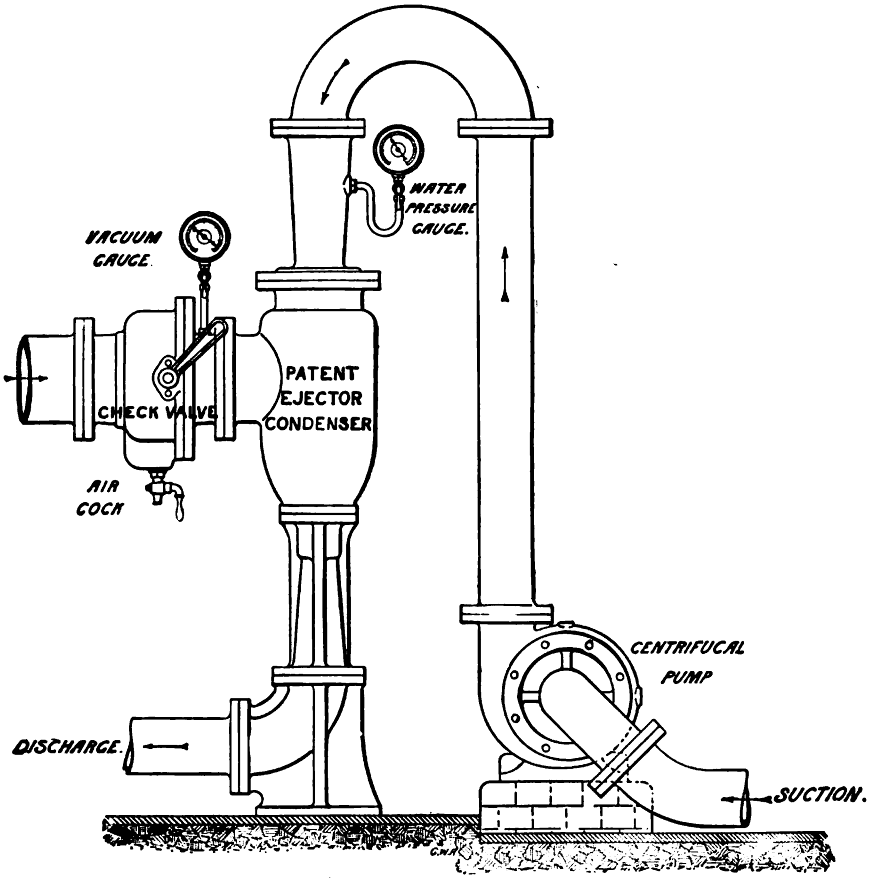


FIG. 66.—Ejector Condenser

either steam or electrically driven. The one shown in Fig. 65 is by Messrs. Mather & Platt, for 1800 I.H.P. It is expensive in first cost; but in large plants that is of no account. It saves the condensed water, apart from the circulating cooling water, so that the clean condensed water can be fed into the boiler, however dirty the condensing supply is.

The jet condenser is much simpler, and is, as a rule, built with the engine and air pump and driven direct from the engine. This is

by far the best practice, even with surface condensing engines. Each engine should have its own combined condenser and pump.

Fig. 66 illustrates the arrangement of ejector condenser with centrifugal pump.

The ejector condenser requires more water than the other two

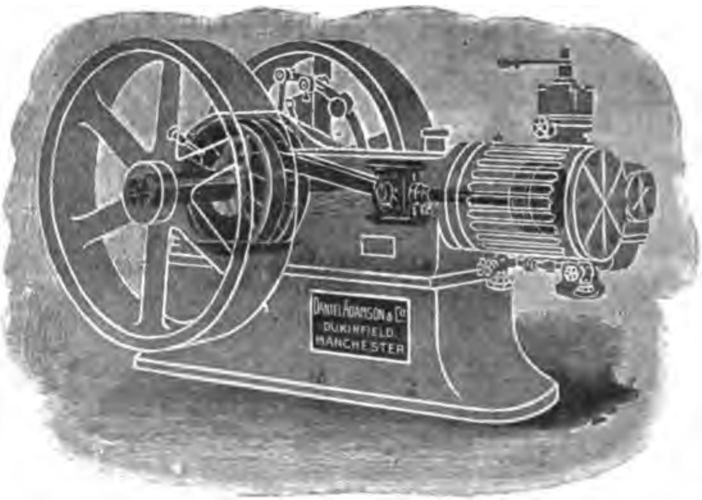


FIG. 67.—Simple

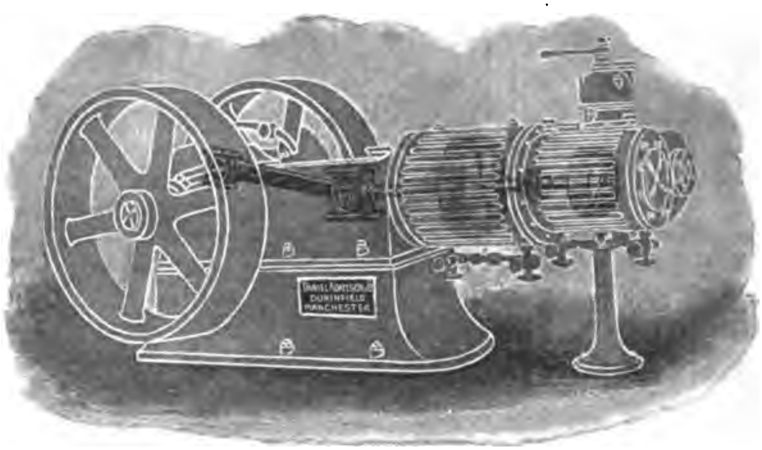


FIG. 68.—Compound
Daniel Adamson's "Ideal" Engine

to give an equally good vacuum ; but its simplicity is so great that, even at the sacrifice of some economy, it is much used.

We now briefly refer to the smaller quick-speed combined plants. We shall only consider one horizontal type. These are sometimes desirable where head room is not to be had. The "Ideal" engine

of Messrs. Daniel Adamson is shown in outline in its simple form in Fig. 67, and in Fig. 68 in its compound form. We shall consider the compounding engines fully, as they agree with what Westinghouse has for many years claimed—the economy of compounding even without condensing.

If steam enters the cylinder at 115 lbs. pressure absolute, and is released at 50 lbs. pressure absolute only 56.5 per cent. of the available energy of the steam is used. If, on the contrary, steam is admitted to the cylinder at 115 lbs. pressure absolute, and released at 10 lbs. pressure absolute, 91.3 per cent. of the available energy of the steam is used, a saving of 34.8 per cent. Of course it is understood that it is only by the use of a condenser that such an extreme expansion can be obtained.

It costs only about 1 per cent. more of fuel to raise the steam pressure from 80 lbs., as ordinarily used in simple non-condensing engines, to 100 or 125 lbs. pressure. So by the use of the higher pressure and compounding, a saving of 25 per cent. of fuel may be effected.

Steam at 115 lbs. absolute has a temperature of 340 degrees. Steam at 10 lbs. absolute has a temperature of 193 degrees. The range of temperature of the steam in the cylinder is then 147 degrees, and during every stroke of the piston this variation of temperature occurs. Of course, the walls of the cylinder do not change in temperature to that extent, but they do remain so cool that the entering steam meets a surface which causes condensation and a lowering of the initial steam pressure. During exhaust, heat is transferred from the walls of the cylinder to the exhaust steam. The amount of loss occasioned by this condensation and re-evaporation is variously estimated at from 0.12 to 0.17 times the square root of the absolute ratio of expansion. Let us take, for example, an expansion ratio of 16. Then $\sqrt{16} \times 0.17 = 68$ per cent. to be added to the indicated steam consumption. Thus it is seen that a point is very soon reached where the losses from condensation overbalance the gain by expansion in a single cylinder. If, however, the steam, after a moderate degree of expansion in one cylinder, can be transferred without the loss of heat to another cylinder, it can there undergo a further expansion without having a harmful range of temperature in either cylinder.

When all things are taken into consideration, the measure of saving to be expected by the use of compound engines, condensing or non-condensing, over single expansion engines under like conditions and equally good constructions, may be roughly placed at from 15 to 35 per cent., varying with conditions. So that while the first cost of the compound is more than that of the single expansion engine, there are conditions under which the larger investment is the more judicious one. These conditions are cost of fuel, steam pressure, and cost of condensing water. If fuel is very cheap, there

will be little in favour of the compound. If fuel is dear, and a steam pressure of 100 lbs. with a condenser, or 110 to 125 lbs. without a condenser, can be used, the saving in fuel may be expected to pay for the additional cost of engine, condensers, &c., in from two to five years.

One feature of this engine is the absence of packing glands between the high and low-pressure cylinders. It is replaced by a long sleeve of anti-friction metal, with grooves in its inner surface to form a water packing.

The governor is of interest, and is shown in Fig. 69. It is

FIG. 69.—Governor of "Ideal" Engine

simple, of few parts, consisting as it does of but one spring, one lever (with adjusting weight) and connecting link to the shifting eccentric. All parts are in sight, and placed at such a distance from the shaft as to be readily accessible.

The dash-pot is to prevent too sudden movement of the weights and levers due to an instantaneous change of load, and avoids violent fluctuations of speed. It also maintains the equilibrium of the force of weights and springs. A change of speed of less than one revolution per minute will cause the dash-pot and springs to yield steadily to the centrifugal force of the weights, changing the position of the eccentric and valve movements, and thereby constantly cutting off the steam so as to maintain a uniform rate of speed.

Ship-Lighting Engines

The vertical type is the favourite for most small direct-coupled plants for ship lighting. I am not including steam-turbines in ship-lighting plants, for the reason that I do not see clearly how the gyroscopic effect is to be overcome.

Many years ago I had to instal some scores of ship-lighting plants, and came across this gyroscopic effect. An armature revolving at 1200 revolutions per minute, and one foot in diameter, has

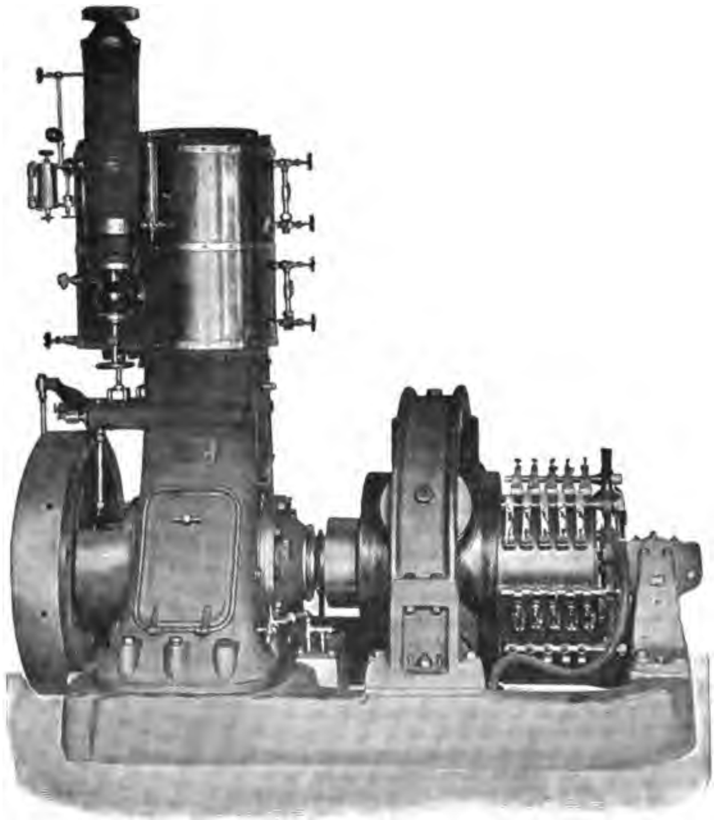


FIG. 70.—B. T. H. Combined Plant

a very decided objection to alter its plane of revolution when the ship pitches and rolls, so much so that the bearings and shaft may become damaged at higher speeds.

The large turbines so successfully used for propelling the ship are another story. The speed is slow and the bearings massive, so that the gyrating effect can be met. Turbine working shall be again referred to.

The British Thomson-Houston Company have brought out a complete line of small high-speed combined plants, from 25 to 75

K.W., shown in Fig. 70. It has a fly-wheel governor. Fig. 71 shows Messrs. Mather & Platt's plant.

For very small sizes, simple single cylinder engines, Fig. 70, are all that is required up to 10 or 12 horse-power; but for large sizes they should be compounded, for they are always run on the condenser in the ship.

FIG. 71.—Mather & Platt Combined Plant

On large ships, where the question of cost is not important and there are plenty of attendant engineers, electric light is always fitted.

Smaller steamships are still lighted by oil lamps. This should not be so at this date; they have the steam, and electric light, if properly fitted, would be a great benefit and really cheaper. A single-wire system of wiring, with plain single-wired fittings, is cheap, durable, and safe, and a simple generator not much trouble or expense in maintenance.

A trading ship, carrying no passengers, might have the following electric lights:—

Officers' quarters	5 lights.
Engineers' „	4 „
Mess-rooms	5 „
Binnacle	1 „
Side lights	2 „
Mast head	1 „
Anchor light	1 „
Bridge	2 „
Deck	4 „
Engine-room	6 „
Stoke hole	4 „

Portable lights—2 in hold, and one group of 5 for illumination when discharging cargo.

A 50-light plant with a 5 horse-power engine, would supply all this easily. A plant of these dimensions must be cheap and exceedingly simple, requiring very little attention. Small engines like this may take 50 to 70 lbs. of steam per horse-power hour, but they are not always running. The great point is to get small engines, requiring little attendance and not readily disabled.

With all these engine problems involved in the generation of electrical energy, it will be readily gathered that in practice the engine questions are of far more importance than the dynamos, and that the best electrical engineers should have a thorough training as motive-power engineers. The popular idea that an electrical engineer should be an electrician is a mistake; his work is purely

mechanical, and in steam engineering or gas engineering, only a very few electrical engineers require to practice the science and arts of the electrician, in designing dynamos, motors, ammeters, voltmeters, ohmmeters, circuits, and other work, where a deep knowledge of electricity and magnetism are required, and sound judgment on electrotechnics acquired by experience. Probably not twenty electricians are engaged in purely electrical work in Great Britain, while hundreds are engaged on steam plants for generating and distributing electricity for sale. They are all electrical engineers, but very few electricians. Young men in entering as apprentices should note these facts; a profound knowledge of electricity and magnetism counts for very little in practical electrical engineering in municipal and other electrical generating works, and less in tramway work.

In many works turning out great quantities of electrical machinery there is no need for more than one or two professional electricians—men who can handle the electrical and magnetic problems arising in the work, calculate out new designs, and supervise the purely scientific work; all the others are mechanical engineers, with exception of a few in the testing room who can read instruments and tabulate the readings, and the wire winders, for armatures, upon whom the good qualities of a machine still depend to some extent.

The apprentice "electrical engineer"—using the term for those employed in actual manufacturing, installation, and generating works —must be trained as a mechanical and steam engineer, with an elementary knowledge of electricity and magnetism, and a general knowledge of the principles of dynamos, motors, wires, switches, instruments, &c., such as is to be found in these volumes. If the young man wishes to be an "electrician," then he need not trouble himself with mechanical or steam engineering, but confine his energy and time to electrical and magnetic studies, the electrical laboratory, test room, and drawing office.

The great mistake made in our technical schools is the attempt to teach too much, giving a very scanty training in many subjects, instead of a thorough training in a few correlated subjects. Before concluding this chapter, I have to refer to several engines of interest.

In Fig. 72 we have an illustration of the gas-engine and dynamo combined by Messrs. Crossley Bros. The dynamo is a multipolar machine with an armature of large diameter, and very narrow in order to obtain a high peripheral speed at the comparatively slow revolutions of the gas-engine, about 220 per minute. In a recent case tenders were obtained for an electric light and power installation, with gas or steam plants as alternatives; the tenders for steam plants included everything, condensers, cooling reservoirs, buildings, chimney-stalk, and all accessories for a complete steam plant for

150 K.W. output. Similarly, the gas plants included everything necessary, gas-producers, buildings, water supply, and tanks all for same output; the cost came out almost exactly equal, about £4000—£26, 10s. per unit. The gas-engine and dynamo combination is from every point of view commendable, but the same can hardly be said of the producers in the market in past years. Messrs. Crossley Bros. have, however, taken up the producer of gas, and in their hands we are likely to have considerable improvements. What is most required at present is a simple reliable producer of gas of a uniform quality, in an apparatus requiring no more attend-

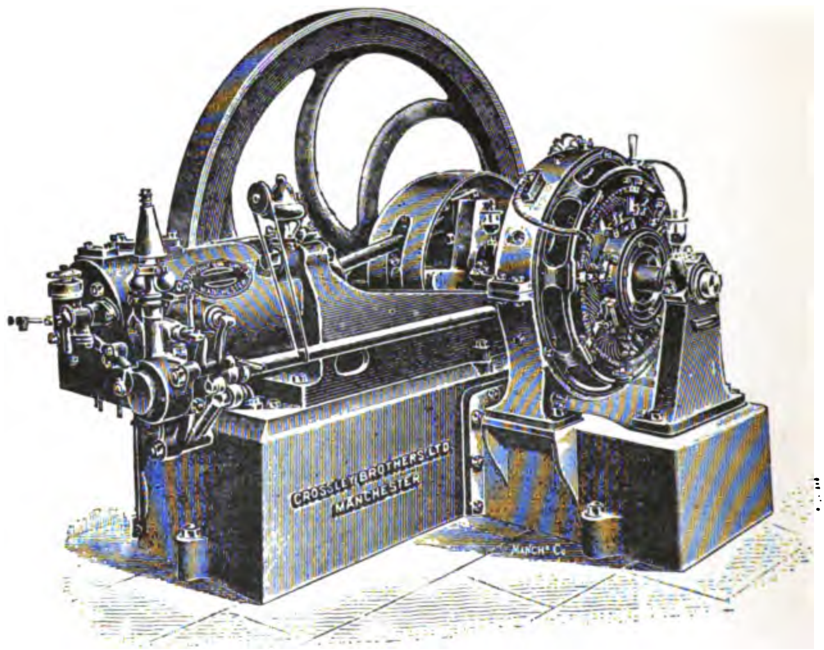
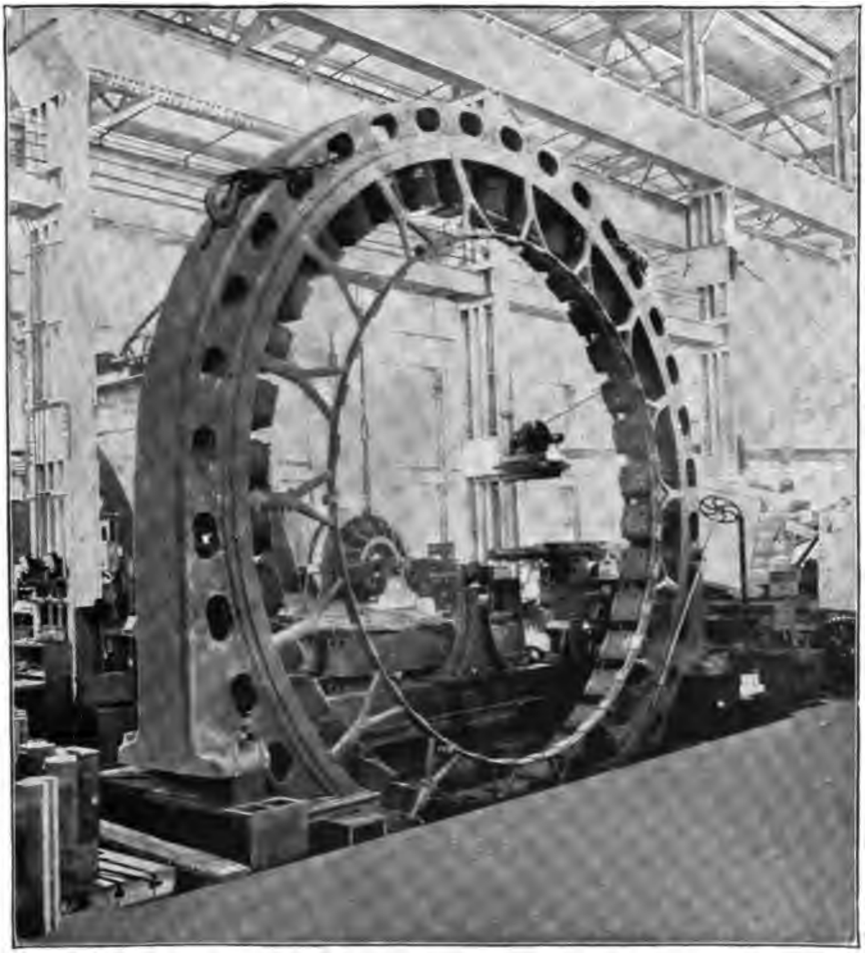


Fig. 72.—Crossley Bros.' Combined Gas-Engine and Dynamo

ance and repairs than a steam-boiler of equal power. This more for small plants; the larger plants can afford to run any kind of producer, as the repairs and attendance in these amount only to a small fraction of the total costs.

We have referred to the adoption of the Körting gas-engine by Messrs. Mather & Platt for dynamos and driving, and shown an elevation of it. In Fig. 73, annexed, is a sectional diagram explaining the operation of this engine more particularly. The exhausting ports in the middle of the working cylinder is a good device, but not new. In the Clarke gas-engine, made twenty years ago in Glasgow, the same cycle and exhausting was used in a single-acting engine, many of which were in use.

This engine is double-acting, and Fig. 73 shows a horizontal



Continuous Current Multipolar Field Magnet.
(The British Thomson-Houston Co.)

section through the motor cylinder and the two pump cylinders, one of which supplies air and the other gas. The length of the piston is practically half the length of the motor cylinder, and the exhaust port is at the centre of the latter, and is uncovered when the piston is at either end of its stroke. Following the exhaust comes a scavenging charge of air from the air-pump, which sweeps out the burnt products, and finally there enters a mixture of gas and air together. The mixture passes a diaphragm, which gives a whirling motion, and makes it act like a plug; it being maintained that the mixture remains at the back end of the cylinder with the pure air in front next the piston. On the return stroke the piston closes the exhaust port, and compression takes place; then the mixture is fired, and the working-stroke results. Both sides of the piston are utilised, and thus two impulses per revolution are obtained, and the crank effort approaches in evenness the turning moment of a double-acting steam-engine. Indeed, in some ways it resembles a steam-engine using gas, and the speed can be regulated by simply opening or closing

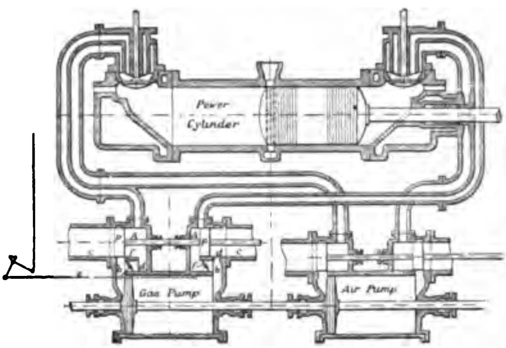


FIG. 73.—Sectional View of Körting Gas-Engine

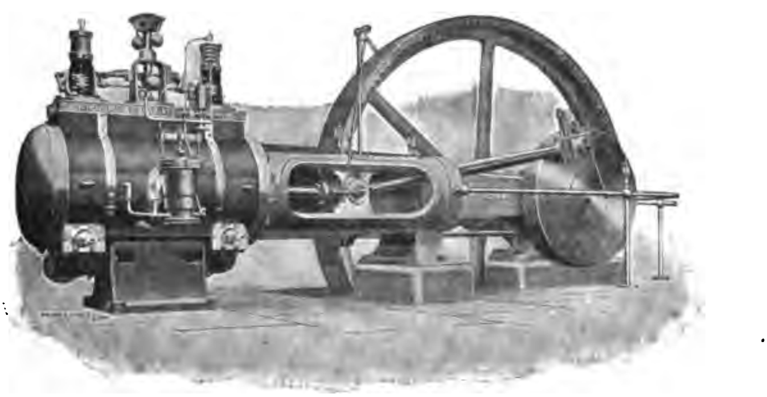


FIG. 74.—Robey Horizontal Engine

the gas valve. In practice the mixture is regulated by the governor acting on a by-pass in the gas suction, in such manner that more or less gas is returned to the gas-pipe, and only a portion of the pump-volume delivered into the motor cylinder, according to the

work to be done. The piston is water-cooled, as well as the jacket and valves.

The engine shown in Fig. 74 is one which has been much used in electrical work. This type, made by Messrs. Robey & Co., belongs to that known as Proell gearing, the steam being admitted by Cornish valves operated by trip gear. The cut-off is beautifully

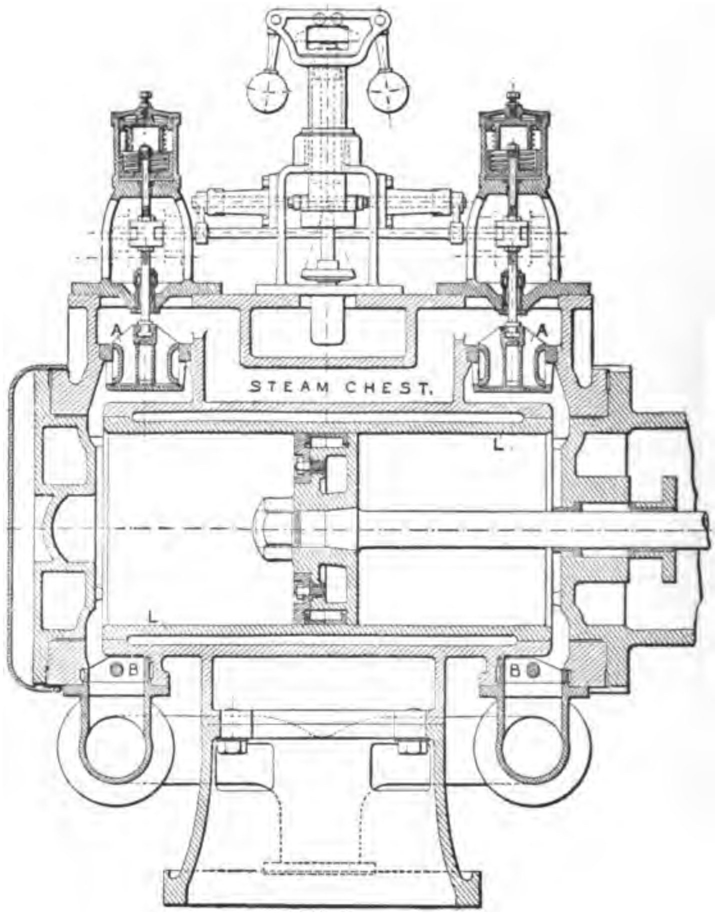


FIG. 75.—Section of Cylinder fitted with Trip Gear

sharp, and the expansion accurately regulated by the governor controlling the time of admission through the valves A A. The exhaust valves B B are operated separately by an eccentric rod and cranks. The cylinder, as may be seen, is steam jacketed, in the sectional Fig. 75. The general arrangement is clear. My own experience of these engines has been very satisfactory in private installations. They require very little attention, and are economical over a long range of load.

Vertical Compound Engine and Condenser

Fig. 76 represents Messrs. Robey's vertical compound high-speed open type of engine and a Westinghouse dynamo combined. This is a back view, showing the jet condenser and air-pump. The fly-wheel is in this case on the wrong end of the engine, for its momentum must be in this position, transmitted through the cranks to the load or dynamo, whereas when the fly-wheel is along-

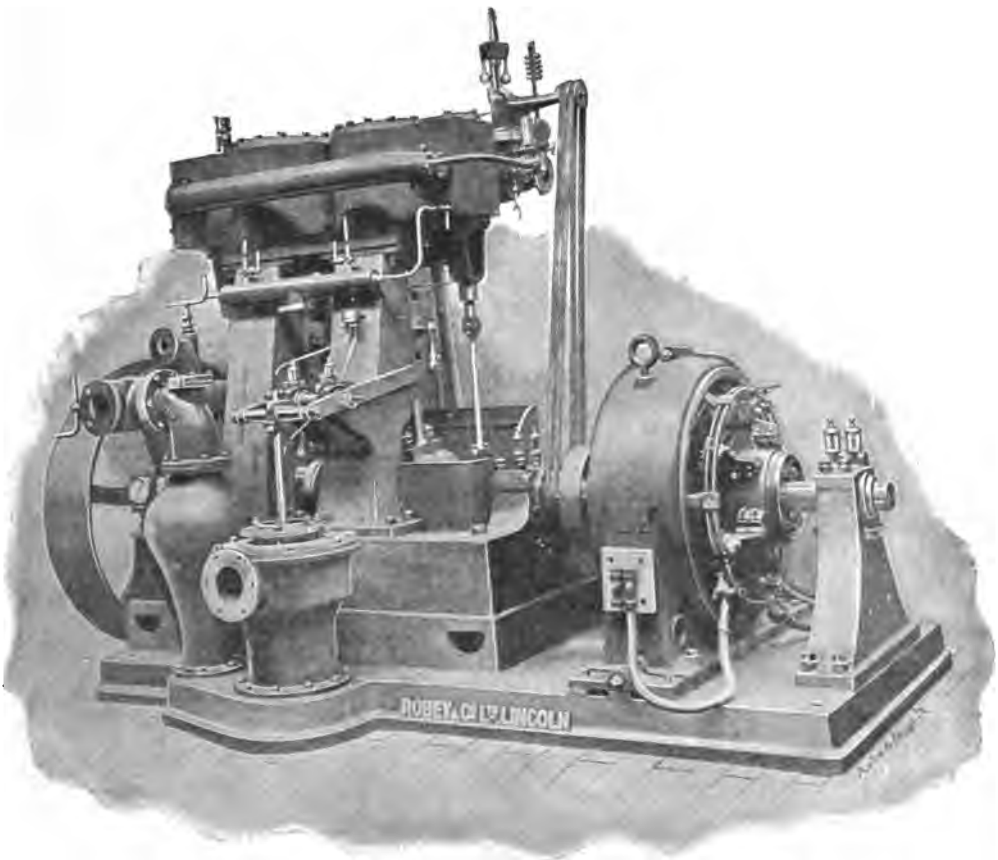


FIG. 76.—Robey-Westinghouse Combination

side of the dynamo on the same end of the shaft, the momentum is transmitted direct to the dynamo without straining the cranks; in fact, the armature should be the fly-wheel wherever possible.

Since writing the notes on steam turbines, it is now known that one of the largest electric traction plants in Britain is to be fitted with steam turbine generators of 6000 horse-power each for the underground railways of London. This is a very significant fact, and one over which the reciprocating engine-makers must ponder seriously. Also the fact that steam turbines are displacing that

most economical of all reciprocating engines, the marine engine. The question was put by a business man about to instal a generating plant, "Why the steam turbine has been so long in the market, and yet so few in use?" And, arguing from that, that there must be some drawback connected with their employment. The delay in their adoption, more generally, does not arise from any difficulties with the turbines themselves, but principally with the class of men who act as advisers, especially to municipalities, who prefer to follow a fashion set by some one or other rather than to take any initiative action themselves. Week in week out from year's end to year's end the majority of electrical journals sing the praises of municipal plants, in very rare cases are any blunders pointed out; in fact one technical journal, which poses as the special municipal organ, holds that no blunders were ever made in municipal engineering more serious than misspelling a word in the specifications. Some straight criticism of the engineering would be more salutary, and might result in the adoption of improvements in a little less time than the ten to fourteen years by which we usually lag behind the rest of the world.

The patents for steam turbines are, or very nearly are, expiring, and yet the turbines are only just being appreciated at their true value in this country. And similarly with the induction alternating motors, it has taken the customary fourteen years to establish their value as commercial apparatus. All this delay cannot be blamed on the customers, users, or purchasers of machinery, but to those who are supposed to be leaders in the profession. The progress of mechanical and electrical science will not be impeded, however, for if the engineers in any country lag behind in adopting improvements, the foreigner immediately steps in front aud secures the benefits of the improvement not only for himself, but also for the people he deals with.

CHAPTER III

ELECTRICAL GENERATOR AND MOTOR CONSTRUCTION

THUS part of our subject, if fully treated, would fill the whole first three volumes and more. We have already treated of the elements of the subject in Vol. I.; we shall now deal more particularly with the practical constructions from the mechanical and wire-winding point of view.

We will divide the subject into three large groups: (1) Continuous Current Machines; (2) Single Phase Alternating Machines; (3) Polyphase Alternating Machines.

With the exception of polyphase machines, the motors and generators are similar machines reversible.

On all of them there are two distinct elements. A field magnet or stator for projecting magnetic force; on the second part, the armature or rotor.

Except in the case of the permanent magnet, some means of magnetising the field magnet or stator must be provided.

And in the case of motors and generators, means for supplying current or producing current in the rotor, and of collecting current from the armature of a generator, must be provided.

We will first study the individual parts and then the whole machine, beginning with magnets. The engineer's magnet is a ring, and has no poles. We have already seen in previous volumes that the polarity of a magnet is of no importance, except in the one case of the mariner's compass, and yet the text-books and teachers hang on to this polarity question, and examiners can fill up a whole paper of questions requiring explanations of a lot of tricks with magnets and their polarity.

The permanent magnet is a piece of steel with a magnetic field of force permanently attached to it; what its internal magnetic condition is, is a matter of no practical importance, it is the external field of force which is useful and of importance. If we take a tempered steel ring and wind a coil of wire all over it, and send an electric current through this wire, the ring will be strongly magnetised, but as a magnet it would be of no use, for it has no external field. If, however, we take a piece out of the ring, we get a magnetic field in the gap as in Fig. 77; and if we put an armature in the gap the armature will be acted upon by this field of force, the armature becoming part of the magnetic circuit itself.

The complete ring is called a closed magnetic circuit, and it will be seen that the ring with the gap filled by an iron-cored armature is as near a closed magnetic circuit as we can make it. And so it is in all motors and dynamos; the magnets are as near as possible rings or closed magnetic circuits.

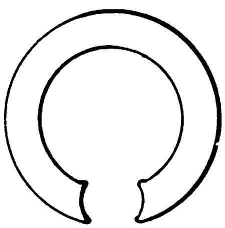


FIG. 77.—Simple Ring Magnet

An American machine, shown in Fig. 78, was actually made with a magnet of ring form with a gap to let the armature into the field—a slight transition, and we get the horse-shoe field in Fig. 79. From Fig. 77 we get a series of fields by combining them in a circle as in Fig. 80, where we get four fields (N, S, N, S) from four magnets, and so we could get any number of fields and form multiple field magnets.

Then, again, we could combine two rings to form one field, as shown in Figs. 81 and 82, and from this are derived many field magnets well known in form.

Then we may have another form of field magnet—first introduced by the author in 1885—an ironclad field magnet, or shell magnet, in which the iron encloses the wire coil.

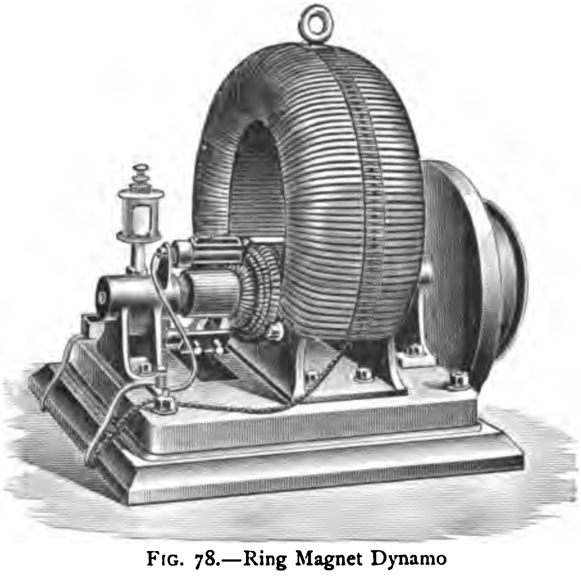


FIG. 78.—Ring Magnet Dynamo

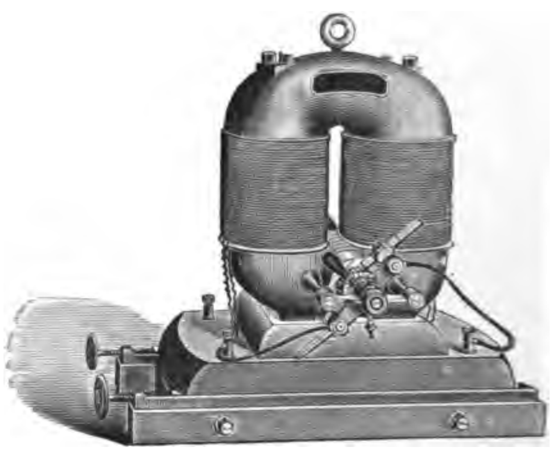


FIG. 79.—Horse-Shoe Magnet Dynamo

Magnets are made with inward projecting cores, and with a very broad and overhanging yoke ring almost enclosing the whole (see page 95, Vol. I.) and called "ironclad" machines, but they are not properly so called. The true ironclad field is shown in Figs. 157, 158, Vol. I., and is distinguished thus. In an ironclad

field magnet there is only one coil for magnetising any number of poles. It may have ten pairs of poles and only one coil. The Kennedy, Mordey, and Warren alternators have ironclad fields, also the author's continuous current homopolar dynamo for direct coupling for very large outputs. This magnet is shown in Fig. 83 in side view and in section. The collecting brushes press directly on the armature bars, there being fifty pairs, one set passing between the outer field casing. The armature bars continually cut the field in one direction. There is no commutation of current, and hence no sparking at any load. The bars are double the number of pairs of

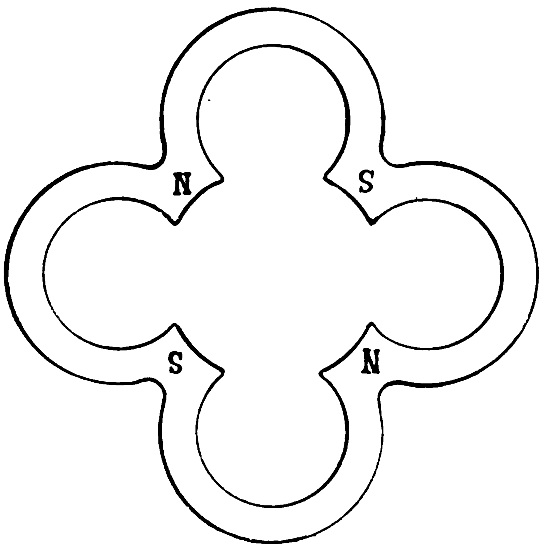


FIG. 80.—Multipolar Field Magnet

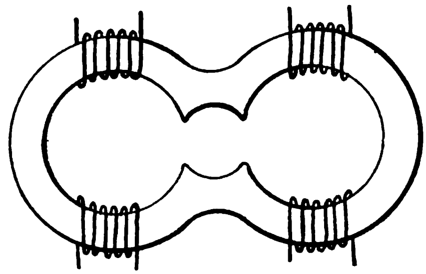


FIG. 81.—Simple Field with Four Coils

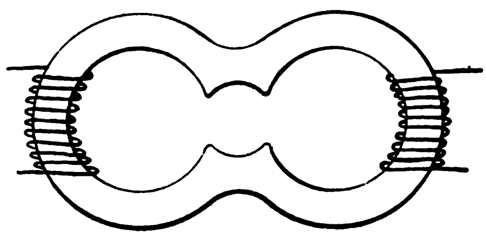


FIG. 82.—Simple Field with Two Coils

brushes, in order to avoid short circuiting. In this machine there are 100 bars, and 50 active in series at any one time. It is designed for 500 volts 3000 amperes at 100 revolutions per minute, so that the magnetic flux will be, in English lines,

$$\frac{500,000,000}{50 \times 100} = 100,000.$$

With a gap flux density of 10 per square inch, 10,000 square inches must be the polar face area at 10 feet diameter, for the inner face is 377 inches, $\frac{10,000}{377} = 29$ inches, as the active length of bars between the field faces. It is, however, better to have the bars shorter and the field stronger, say 12 per square inch. Total area of pole face would then be $\frac{100,000}{12} = 8333$, and $\frac{8333}{337} = 22$ inches, as length of bars under the poles. The bars would be $3\frac{1}{4}$ inches broad and half-inch thick.

The enormous labour and expense of constructing large railway generators is obvious to anyone contemplating the ordinary design. A machine to give 500 volts and 3000 amperes would have a massive laminated armature and a 10 or 12 poled field magnet in

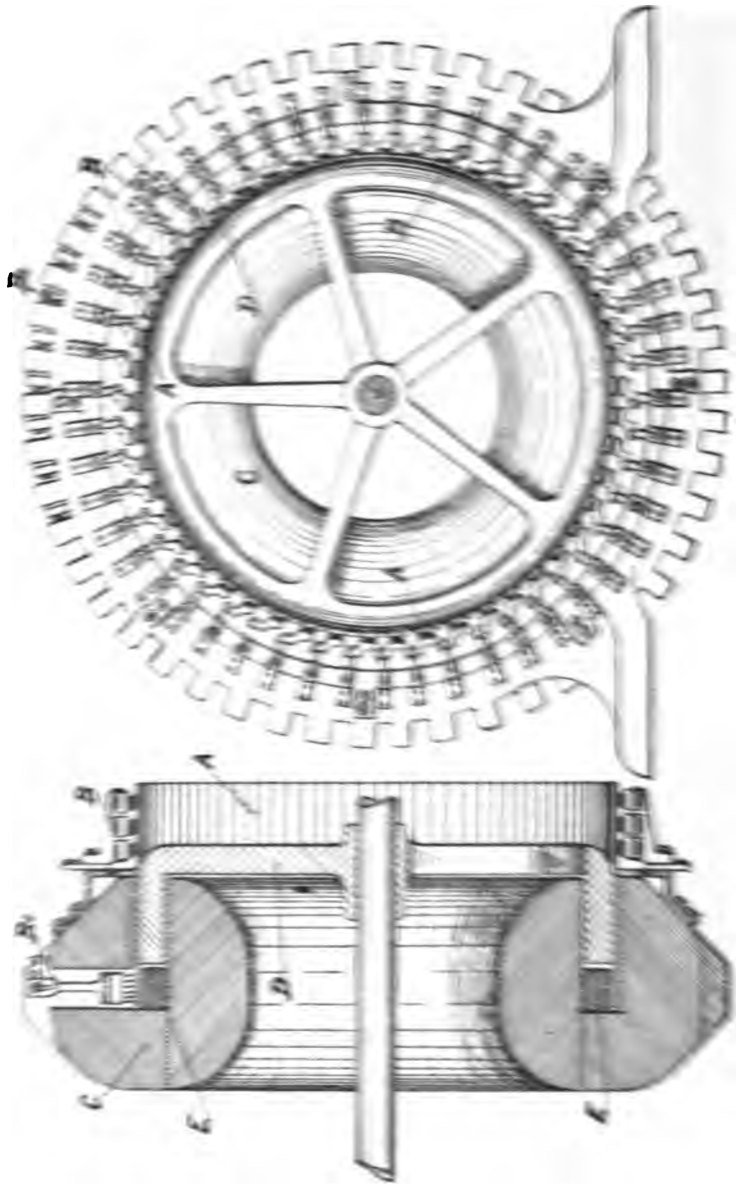
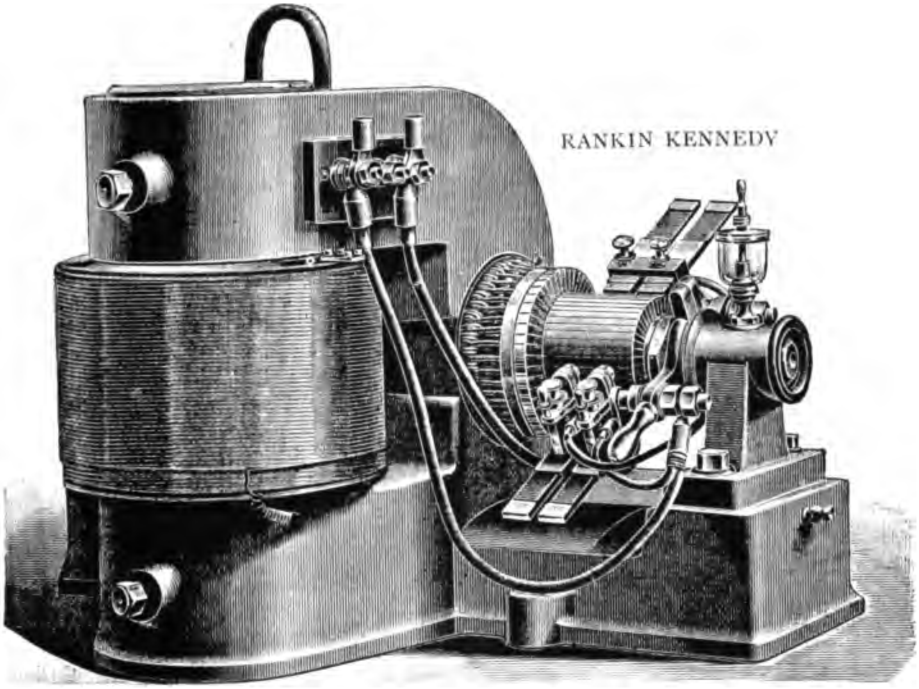
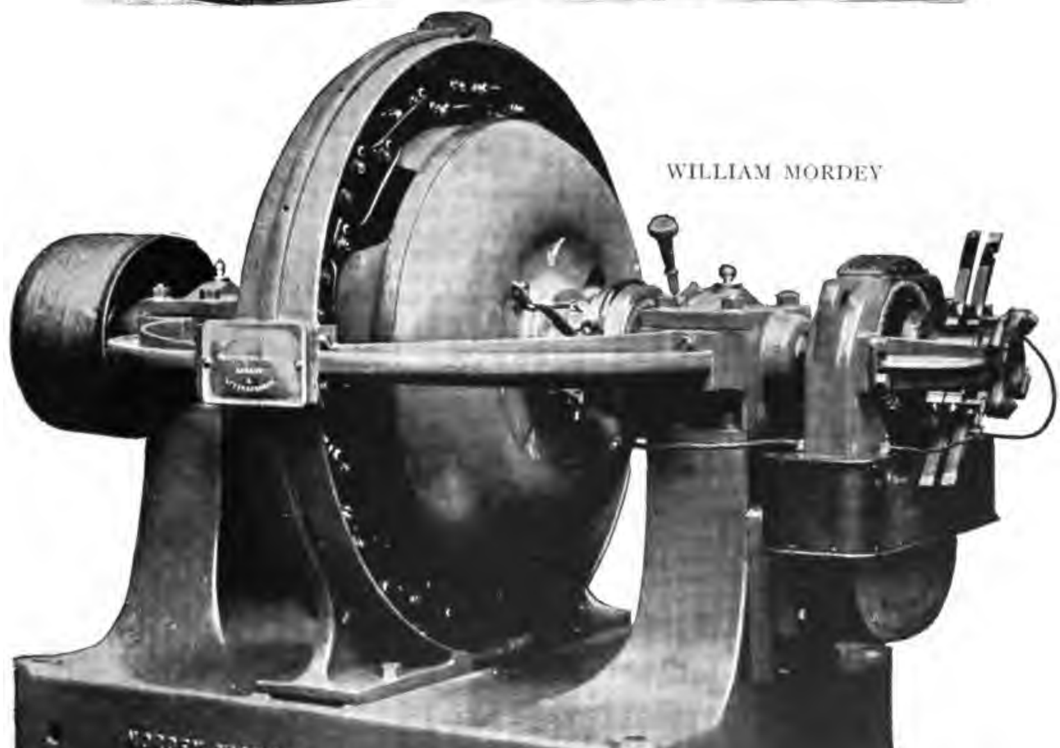


Fig. 81. Kennedy's High Pressure Homopolar Dynamo

general design like that shown, a BTH field for 1500 KW in the plate.

A laminated armature is shown in Fig. 82 of Westinghouse type, and two of the magnet coils in Fig. 83. They can be compared





Typical Single-Bobbin Continuous-Current Generator, and Single-Bobbin Alternator

Homopolar Machines

The enormous labour and expense of constructing large railway generators is obvious to any one contemplating the ordinary design. A machine to give 500 volts and 3000 amperes would have a massive laminated armature, and a 28 or 30 poled field magnet in

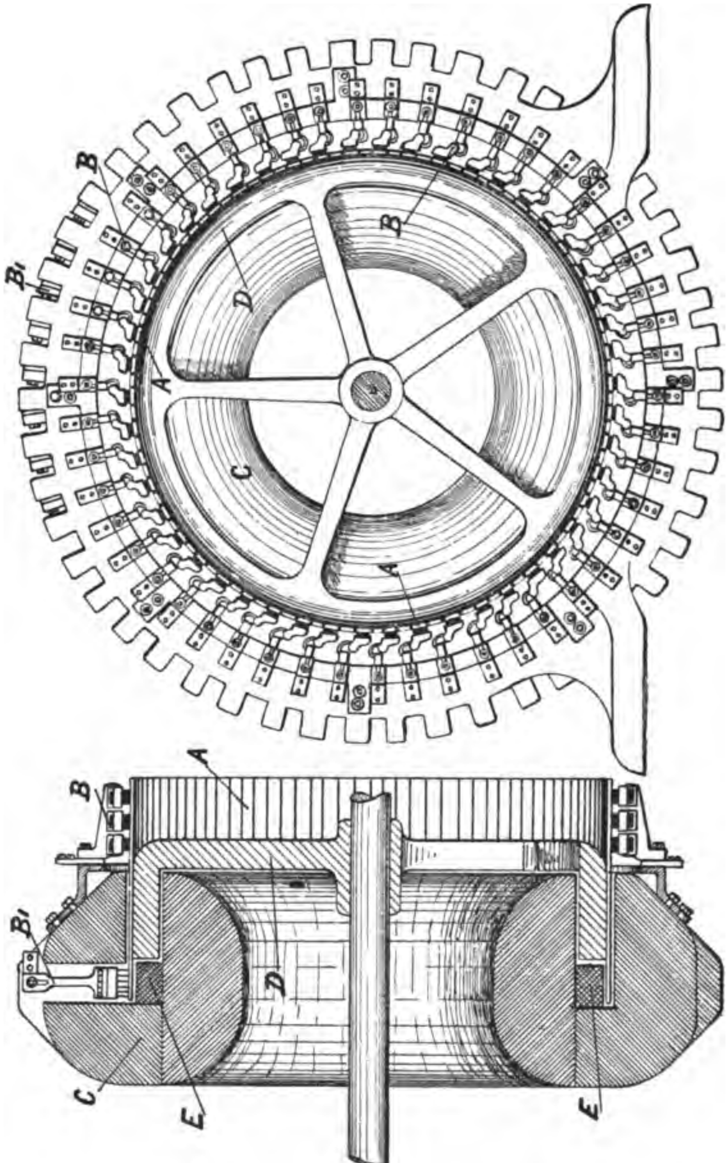
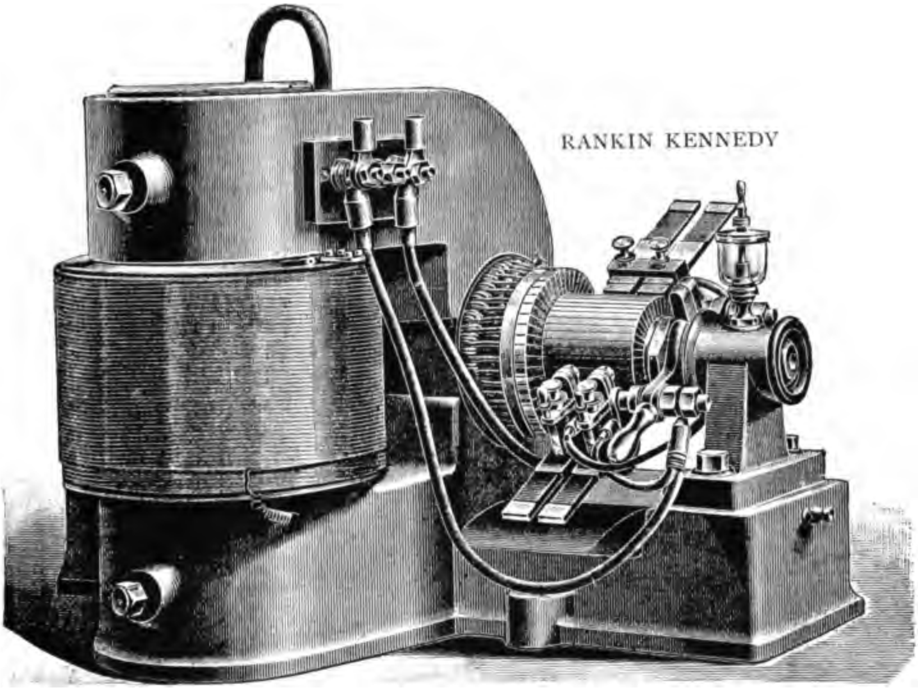


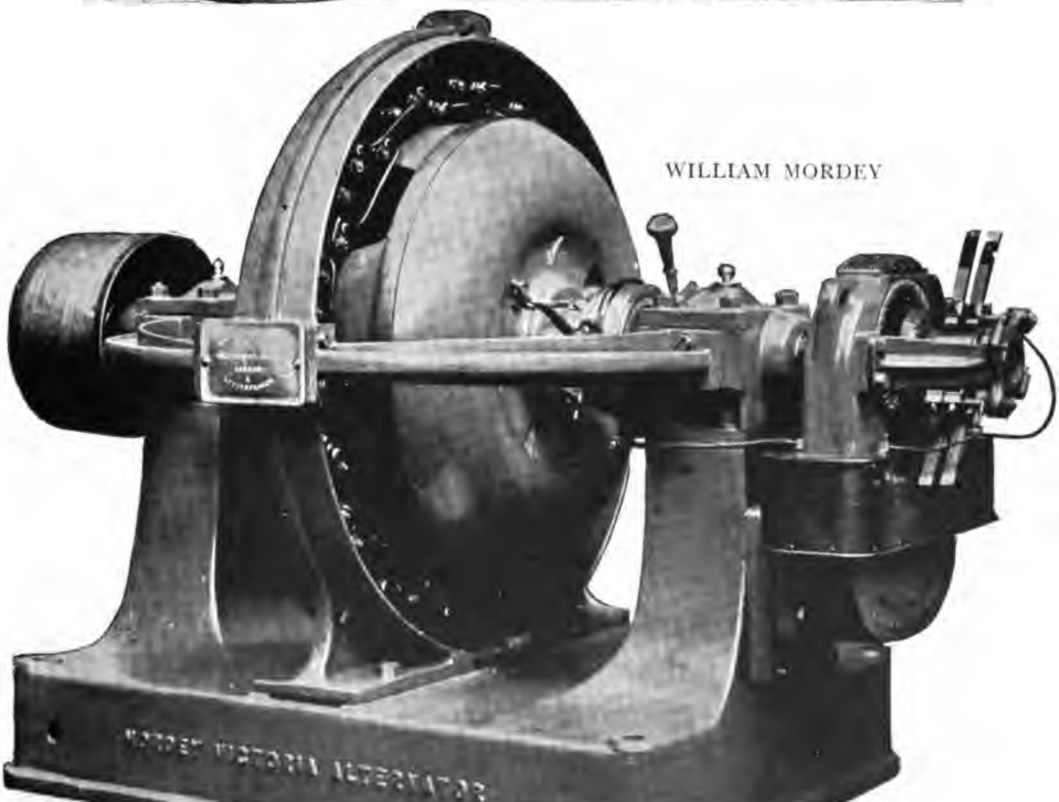
Fig. 83.—Kennedy's High-Pressure Homopolar Dynamo

general design like that shown, a BTH field for 1700 KW in the plate.

A laminated armature is shown in Fig. 84 of Westinghouse type, and two of the magnet coils in Fig. 85. They can be compared



RANKIN KENNEDY



WILLIAM MORDEY

Typical Single-Bobbin Continuous-Current Generator, and Single-Bobbin Alternator

with the simple design of the unipolar machine. Professor S. P. Thomson prefers to call this type homopolar, and, in deference to him, we must agree to the term.

Field magnets with multiple poles and coils acting upon wound armatures requiring immense commutators, such as are common now for these large outputs, are exceedingly expensive machines to construct, and when any part requires renewal the cost and labour are very great. Consideration of these points will convince engineers

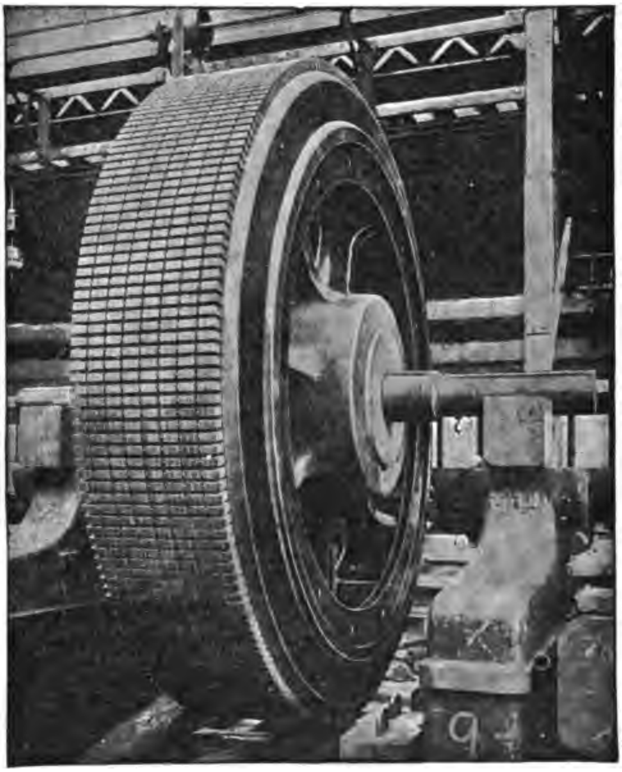


FIG. 84.—High-Pressure Multipolar Dynamos, Armature Core

in the future that although it is the standard practice at present for large outputs to simply multiply the poles and produce a machine which is simply 10, 12, or 20 small machines combined in one. To arrive at a better magnetic circuit design for large powers, we must adopt the unipolar (or homopolar) principle, as shown in my design, Fig. 83, for large power. In order to understand this principle, the student may refer back to Vol. I. Fig. 137, page 108, and then study Figs. 86, 87, 88, 89, and 90 here shown. This is a design for a low-pressure moderate-speed homopolar dynamo. I have long advocated their adoption, but without success, due mainly to the

fact that only those engaged in the manufacture of the largest machines could take up their construction, and these people have only at this date just arrived at standard multipolar types with all that design requires, and although costly it is efficient and works fairly well, so that no one is at present prepared to venture upon the introduction of a radically new design. But sooner or later other firms may arise and start afresh with these homopolar designs and eclipse the older types, the immense business now coming on in large electrical works requiring large units could easily be diverted

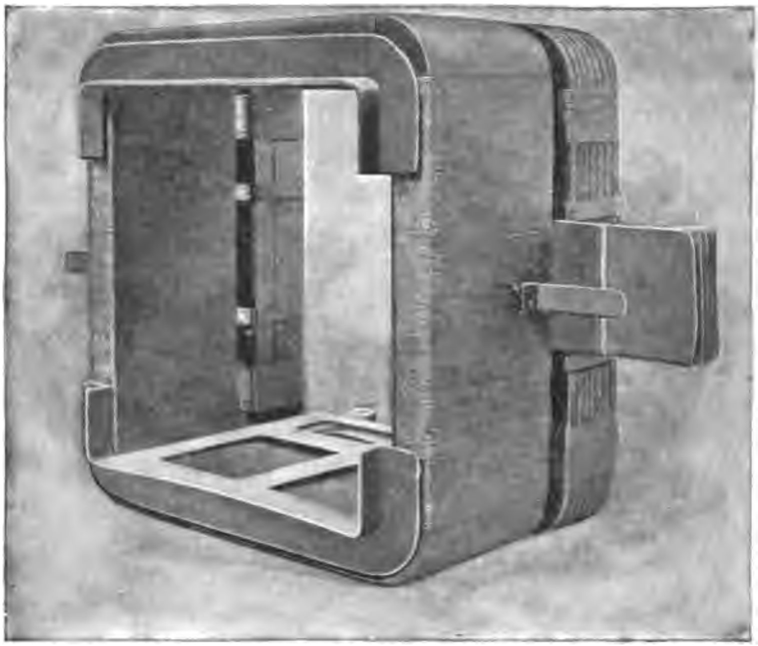


FIG. 85.—Pair of Coils for Multipolar Field Magnet

by the introduction of large generators in which there are no laminations, no commutation of current, a simple cast-steel field magnet, a fly-wheel armature, and no complicated armature winding.

Presently their field of application is in large current low pressure, working 10 to 20 volts.

A machine with an armature 12-inch diameter, and 12 inches of bar under the poles, gave 12 volts and 1000 amperes at 1000 revolutions per minute. The following description will explain the machine further :—

The conductors forming the armature winding are laid parallel with the axis of, and all round the periphery of, a drum or cylinder of soft iron, and firmly bound thereon; the conductors are flat

copper bars insulated from the iron and from each other, forming a shell on the iron drum like the staves of a barrel.

With reference to the figures, in which the same reference letters apply to the same parts in different figures—

Fig. 86 is a side elevation of a homopolar dynamo according to my design.

Fig. 87 is a longitudinal vertical section.

Fig. 88 is an end view partly in section through X Y.

Fig. 89 is a vertical section through W V.

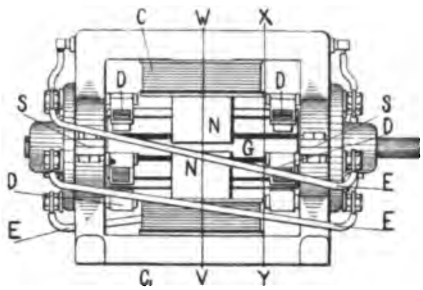


FIG. 86.—Homopolar Dynamo Complete

Fig. 90 is a diagram in which the armature winding is spread out flat, showing the brushes D and external series of conductors E connecting the armature bars in series, five bars in series, all adding their electric pressures together.

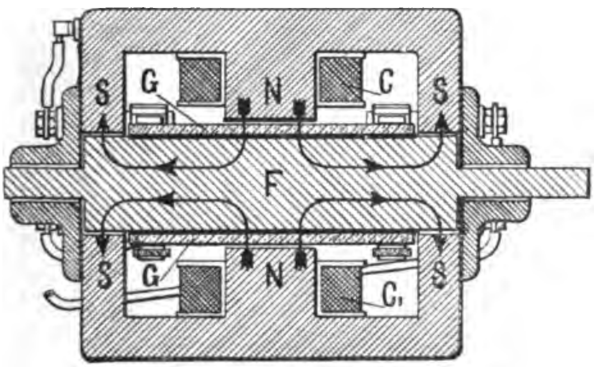


FIG. 87.—Longitudinal Vertical Section

Referring to Fig. 86, the field magnet has three polar tunnels S N N S, a central one N carrying the field coils C C_1 and two similar side poles S S; the armature bars G G G are embraced by the central pole only, and do not extend through the side poles. The armature core consists of a soft iron or steel cylinder, and the conducting armature bars G G G insulated from the cylinder, and from each other, are fixed by insulated screws or rings and binding bands to the middle part of the armature core; the end of the armature bars project beyond the middle pole far enough to enable the collecting brushes D D D to be conveniently applied at both ends. These brushes are connected in series by the external conductors E E E screwed to the brush-holder spindles. In Fig. 87 the longitudinal section S S, N N, and S S are the three magnet poles, F is a section of the armature core of steel or iron, G a section of the armature bars. The field magnet is excited by the two coils C and C_1 placed over and under the middle pole N N.

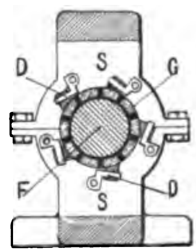


FIG. 88.—Section through X Y

The arrows on the section of the armature core indicate the paths of the magnetic flux from the middle pole N to the two side poles S S, forming a unipolar magnetic field N N, in which the bars G G of the armature rotate at N N, thus continually cutting the lines of magnetic force in the same direction, and setting up an electric pressure in the bars making their ends positive and negative electric poles.

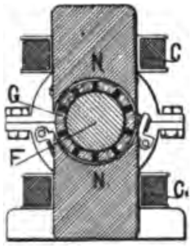


FIG. 89.—Section through W V

Fig. 88 is a vertical transverse section through X Y of Fig. 86, in which D D are the brushes and brush holders, whereby the armature bars are joined in series and electric current collected as the armature rotates; F is a section of the armature core, and S S one of the side polar ends of the field magnet. The vertical section through W V shown in Fig. 89 shows the section of the armature core F, the armature bars G, and the middle pole N, with the two exciting coils C C_1.

The collecting brushes D D D are carried on insulated spindles, and spaced equally round the armature, as shown in Fig. 88.

Fig. 90 is a diagram illustrating the principle of this invention, and the manner in which it is carried into practice. In this figure the armature has five active bars, G G G G G in series, and five pairs of collecting brushes, D D D D D. The diagonal lines E E E with arrows show the fixed external conductors connecting the armature bars in series; the number of bars is double the number of pairs of brushes, in order that there shall be an insulating gap between the armature bars in series; and if the conductors are narrow, three bars per pair of brushes are necessary.

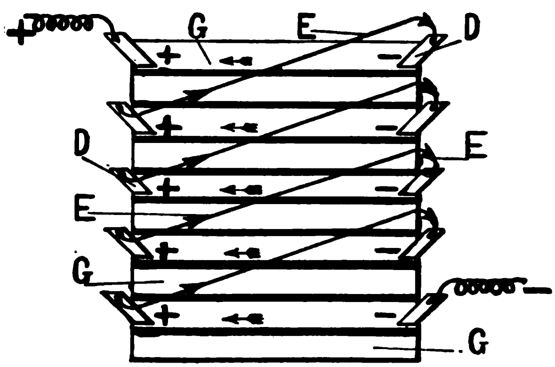


FIG. 90.—Homopolar Series Winding, Kennedy

The bars may be arranged radially to form a disc between two polar discs or rings, and the brushes applied to their inner and outer ends.

Another type of field magnet of use in some cases was patented, Specification No. 1640, in the year 1882. It has been re-discovered and patented many times since then quite recently in America, where it is being pushed forward. It is shown in Fig. 91. The poles are not arranged as in ordinary four-pole machines, as will be noted. Not N S, N S, but S S, N N, with four

brushes, the two circuits of a three-wire system can thus be obtained.

Referring to the figure, the brushes on the outer wires supply

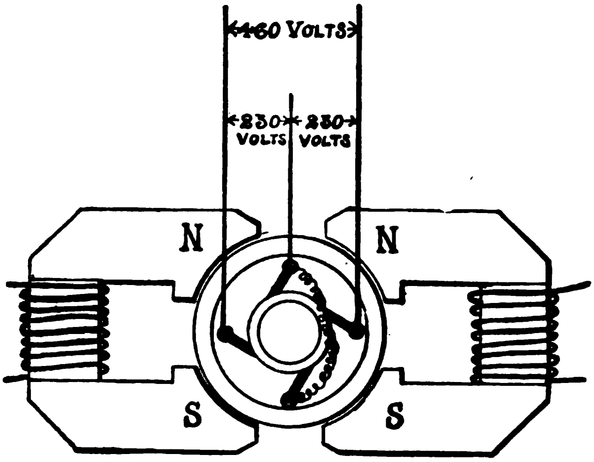


FIG. 91.—Kennedy's 3 Circuit Dynamo

pressure at the full volts, say 460, and on the middle brushes a pressure of 230 volts is obtained, thus working a three-wire system.

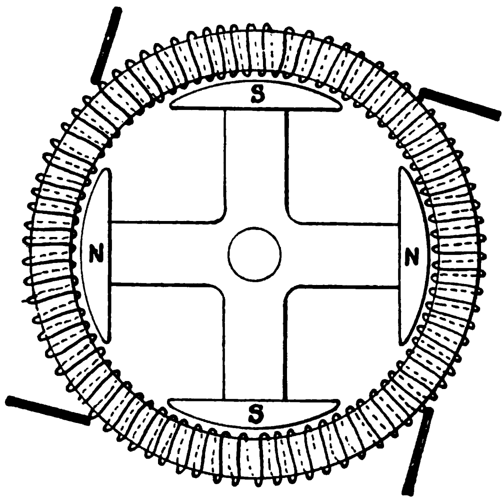


FIG. 92.—Internal Fixed Magnet Dynamo

The middle brushes set up no disturbances whatever in the field, and are sparkless so long as the load on each side of the system is fairly balanced.

Similarly a five-wire system can be formed by having three pairs of poles and five sets of brushes.

The coils sweeping across the gap between the similar poles N N or S S are not generating E.M.F.; the middle brushes do not, therefore, cause any trouble by their short-circuiting these coils, and there is neither any polarity nor magnetic distortion of the field caused by the current entering or leaving the brushes 3 and 4.

Another form of field magnet now much in use has the exciting

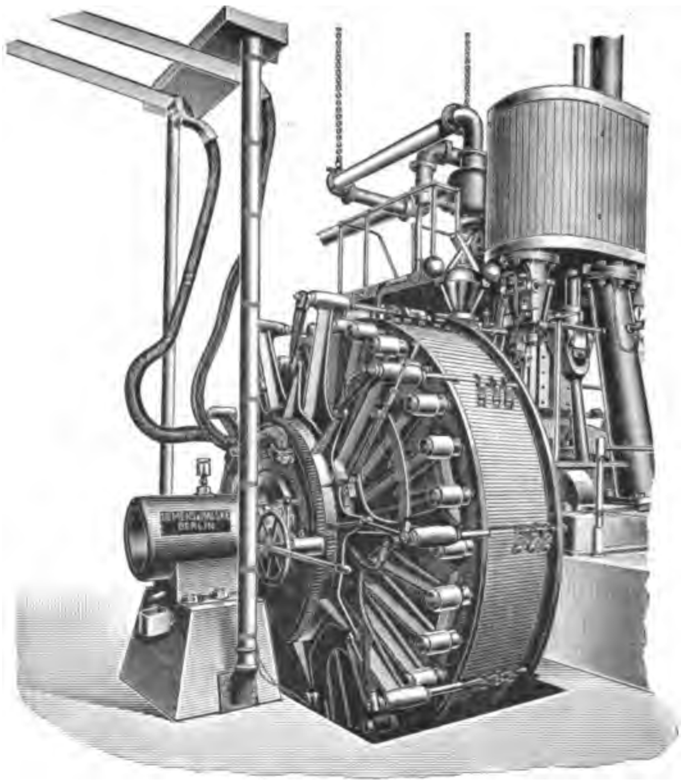


FIG. 93.—Internal Fixed Magnet Dynamo by Siemens & Halske

coil fixed so that only the magnetic core rotates, and there is no wire or electric conductors in motion in the machine. This type is only of use for alternating current generators.

Another type of field magnet is used on the Continent largely, shown in diagram in Fig. 92, and in a large direct-coupled dynamo and engine in Fig. 93. Here the field magnet is fixed inside of the armature, which rotates, and the outside of the armature bars are bared and turned up truly, to be used for commutating, the armature being gramme ring type, with internal slots and one layer of conductors on the outside.

In the steam-turbine combination of the De Lavalle type the

dynamo shown in Fig. 33, p. 48, is double, with a double field magnet, in order to balance the torque on the small driving pinion on the turbine shaft. It also gives a ready combination for obtaining two pressures, 400 and 200 volts or thereabouts. Another dynamo for two circuits, which may be so used, is shown in Figs. 94 and 95, in plan and elevation.

In this machine a central coil, A^1, energises two fields, each

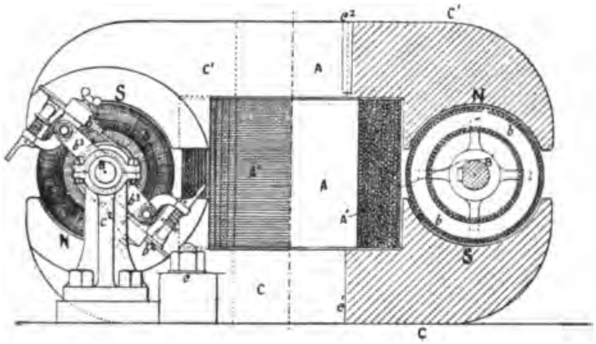


FIG. 94.—Elevation

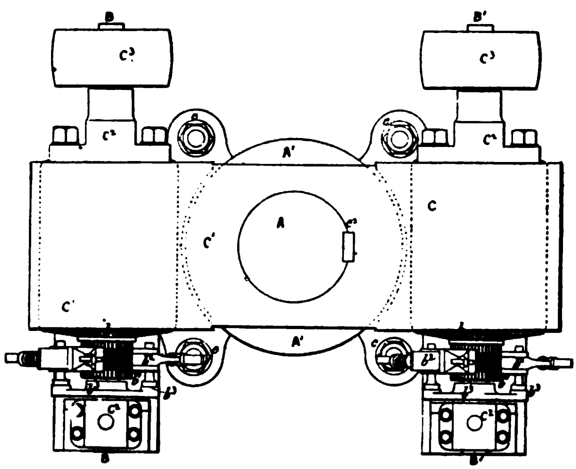


FIG. 95.—Plan
Double Field Magnet Dynamo

containing a separate armature, *b*, *b*. It is arranged for belt driving, and it has been used for twin-screw boat propulsion, giving an advantage in allowing the use of two or four screws. It is found better to run these motors at high speeds, but at high speeds the screws must be small in diameter; therefore to get the necessary thrust-surface multiple screws are employed.

The electric propulsion of boats will be again referred to in next volume.

Ironclad Magnets

The Lundell motor has an iron-clad type of magnet, as shown in Fig. 96, one coil magnetising the two inward projecting poles. The

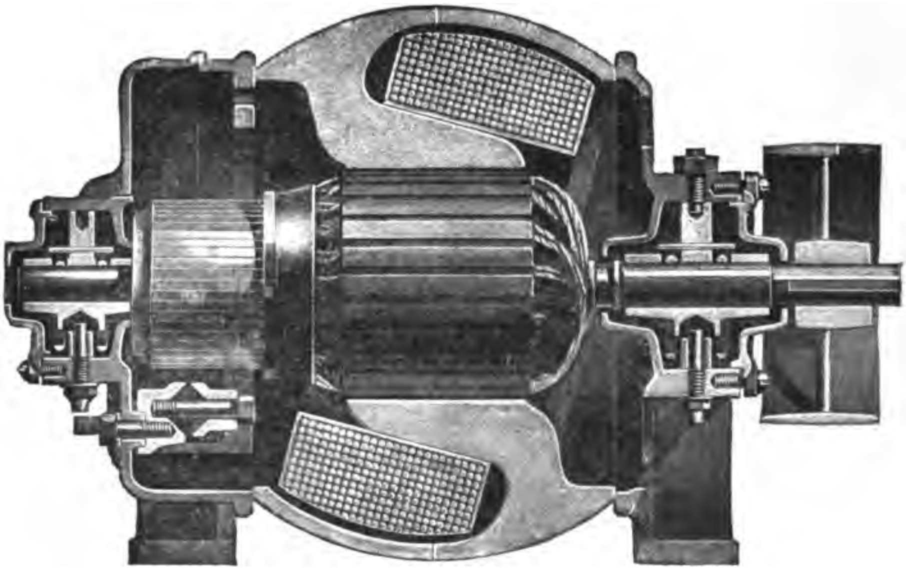


FIG. 96.—Ironclad Field Magnet

Lundell dynamo field magnet also has some features of interest; it is shown in cross sections, Fig. 98. The design is intended to counteract the cross induction of the armature. The armature current has, as is well known in the art, a demagnetising and cross-

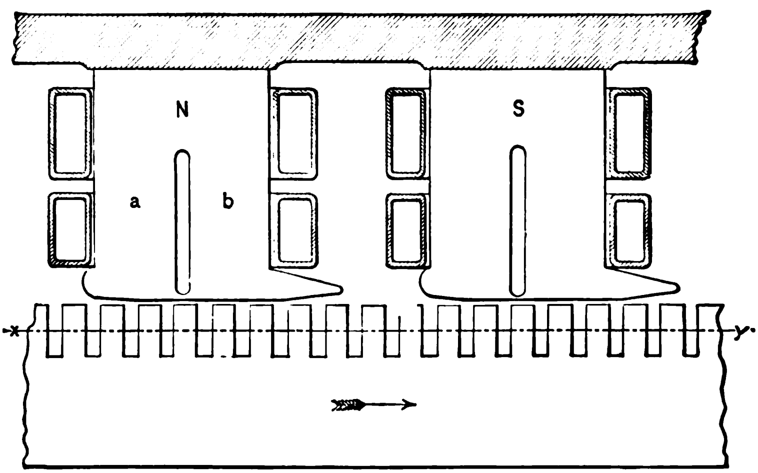


FIG. 97.—Diagram of Lundell Magnet

magnetising effect upon the field poles. The demagnetising effect (due to the armature current between the double angle of lead of

the brushes) can readily be compensated for by compounding, but the cross-magnetising or distorting effect is not so easily overcome. The cross-magnetising force of the armature causes the magnetic flux, with increasing load, to diminish at the pole corner where the commutation takes place, and to increase at the opposite pole corner; or, in other words, it causes the magnetic flux to shift between no load and full load, necessitating a shifting of the brushes in the larger size of dynamos, which depend upon field strength for sparkless commutation. To overcome this difficulty many remedies are employed, some of which are exceedingly complicated and expensive. The usual method is to employ extra strong fields with a concentrated pole flux and comparatively large

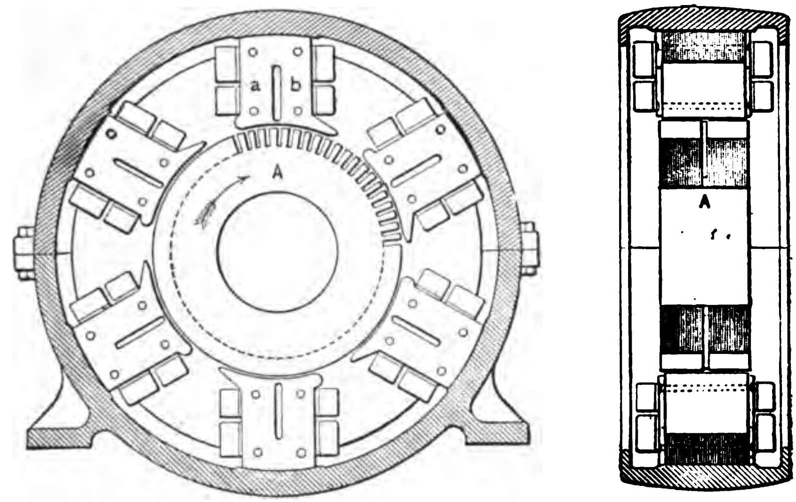


FIG. 98.—Sectional Diagrams of Johnson-Lundell Patent Field Magnet

air gaps, which method only diminishes but does not cure the evil. Strong fields are expensive, on account of the increased size and weight of frame and wire they involve. Large air gaps are expensive for the same reasons, and are, furthermore, inefficient.

Fig. 97 is a developed view of a pair of pole pieces, a part of the yoke and a part of the armature core in a 50-kilowatt engine-type machine.

Referring to Fig. 98, A represents an armature of the machine, which in this instance is designed to rotate from left to right. It is of the usual slotted type. The field magnet cores are divided, as shown, into two parts, *a* and *b*, of practically the same cross section. The pole face of *a* is of an area only slightly larger than the cross section of said part, whereas the pole face of *b* is of about twice the area, this increased area being due to a long wedge-shaped polar extension with which the core *b* is provided. The poles are

built up from sheet-iron punchings, and are so designed that they may readily be turned around in case it should be desired to run the armature in the other direction.

To better understand the fundamental feature of this construction, it may be well to examine Fig. 98, with a view as to what will

FIG. 99.—Field Magnet of Lundell Generator

happen if the field magnet is slowly energised from an outside current while the armature is standing still. With a weak magnetising force, there will be a practically uniform magnetic density under the entire pole face. But as the magnetising force is increased, we will find that the magnetic density under the pole face of *b* will soon cease to increase in the same ratio as the density under the pole face of *a*. In fact, the density under *b*, when the magnetising force has reached a certain point, will remain almost constant as

compared with the density under *a*, which still increases with the magnetising force. This is due to the fact that the core *b* has become saturated on account of its small cross section as compared with its large polar area, whereas the core *a* is far from saturated, and is still very receptive of magnetising force.

From the above explanation it will be apparent that if the field poles are so proportioned that the core *b*, and each part of the polar extension of *b*, is just saturated from the shunt ampere turns alone, or when the machine is running on open circuit, the cross-magnetising force from the armature as well as the series ampere turns round the cores with increasing load, will only have a very slight effect upon the core *b*, and will only slightly increase the magnetic density under its pole face. But the series ampere turns will quickly change the density under the pole face of *a*, as the core

FIG. 100.—Field Magnet Core and Coils

a is not saturated, and therefore sensitive to changes in the magnetising force.

The compound winding, or series ampere turns, will consequently strengthen the magnetic density under the pole face of *a*, at which point a strong field is needed to secure sparkless commutation.

Fig. 99 shows this field magnet core, and Fig. 100 one of the field cores with a main and shunt coil in place.

Fig. 101 is a complete view of the Lundell generator viewed from the commutator end, as made by the Johnson-Lundell Electric Traction Co., and Fig. 102 shows the armature and large commutator ready for drawing on to the engine shaft.

Field magnets are becoming standard patterns of this inward projecting core type, and it does not seem that the many special designs of magnets (with this exception) and armatures are better than the plain cores and plain winding so far as efficiency and

sparklessness goes. A powerful field is the best safeguard against trouble, and in the end is as cheap as any other device.

As for motor magnets, the fire-insurance rules encourage the use of enclosed motors. Hence the four-polar enclosed motor is adopted, although it is not the cheapest and best of small motors.

In the adoption of electrical driving of machinery in works by

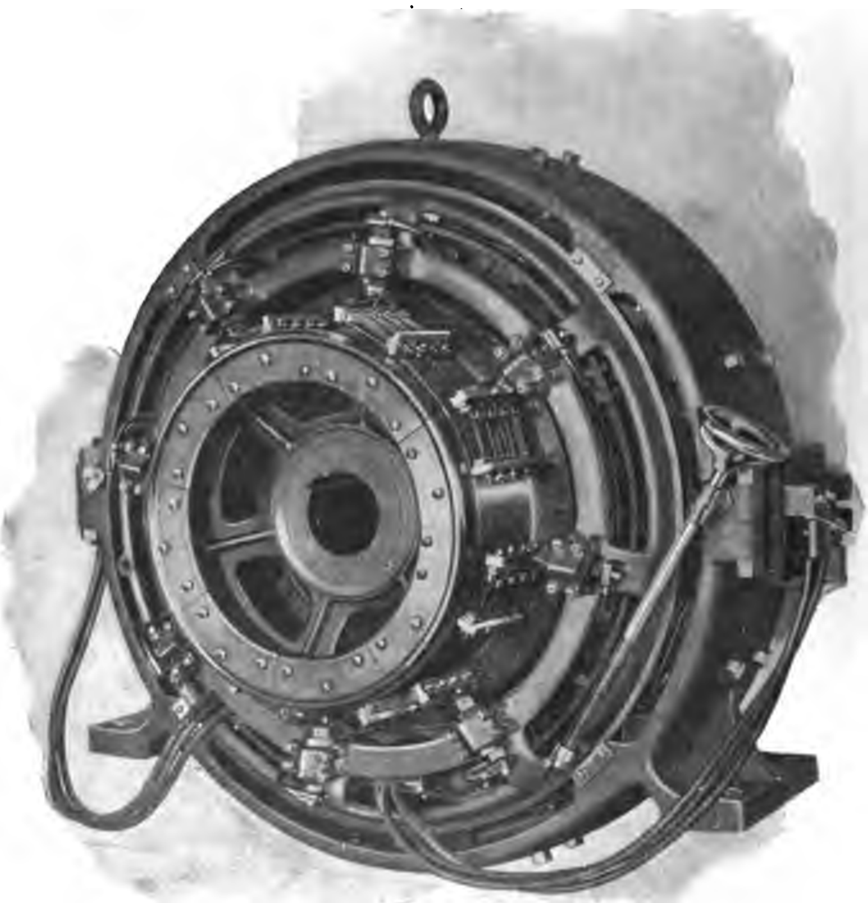


FIG. 101.—Johnson-Lundell Generator

electro-motors, the cost of the motors often stands in the way of its proper application, for to carry out this system perfectly each machine should have its own motor, shafting, belts, and pulleys being abolished as far as possible. This means small motors, for in most cases machines require small powers, the greater majority between half and five horse-power. Many makers consider these

hardly worth constructing, but they are really worthy of attention. Small machines must be costly to construct for 200 to 250 volts pressure to meet the common public supply systems, but in most cases of electric-motor driving the current is generated cheaper on the spot by an isolated installation, in which case the pressure may be 110 volts alone, or 110 and 220 volts on a 3-wire system, so that

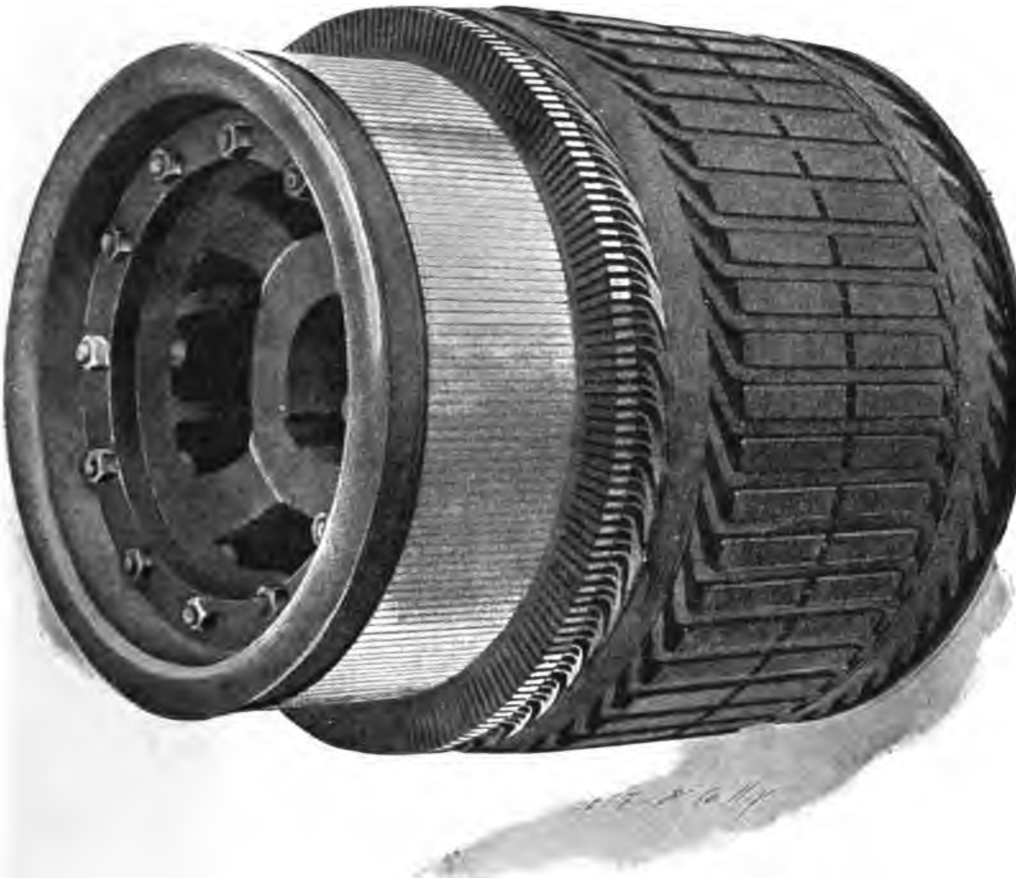


FIG. 102.—Armature of Johnson-Lundell Generator

small motors could be run on the lower pressure. The cost of a small machine depends to some extent upon the design of the field magnet. The present fashion in enclosed fields with inward projecting poles is costly, and presents few counterbalancing advantages in small sizes, if any at all.

The field magnets of dynamos, when made of iron stampings entirely, are used only for smaller machines; but many large machines are built with cast-iron yokes, and bundles of iron stamp-

ings for pole-pieces. Fig. 103 shows one of these stampings from Messrs. Sankey & Sons' lists. The small holes are for soft iron

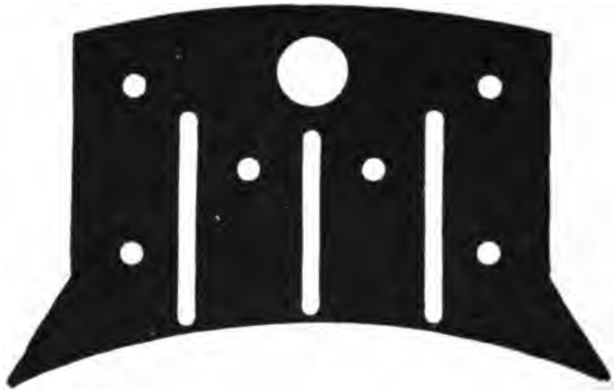


FIG. 103.—Field Magnet Stamping

rivets to hold the bundle together; the large hole is for a bolt to bolt the bundle into its place; and the slits are intended to diminish the cross magnetisation.

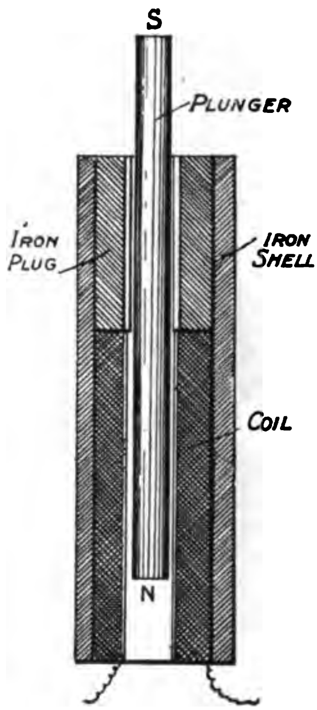


FIG. 104.—Ironclad Coil and Plunger

Before leaving the subject of magnets, a form of coil and plunger, designed to give the maximum effect with the least current, may be referred to, and is shown in Fig. 104 in part section. The coil is surrounded by an iron pipe, and the entering end is fitted with a plug of iron to fit easily over the plunger; this plug may have a brass liner to keep the plunger from sticking. For many purposes, where a great pull over a considerable stroke is required, this form of magnet will be found useful.

The next most important part of a dynamo electric machine is the armature. The almost universal adoption of the toothed armature proves its superiority, and the end-connector bar-winding for heavy currents and former-wound coils has led to the universal adoption of the drum in preference to the ring armature.

The armature core is built up of sheet-iron stampings. Fig. 105 shows a plain stamping for a smooth-core drum armature; the shaft fits into the bore and over a key in one of the prongs; the spaces between are supposed to act as ventilators for air cooling. Fig. 106 represents

a small stamping, with notches and a key-way. Fig. 107 is a stamping for a medium-sized armature, with two inward projecting prongs to act as keys sliding into slots in the shaft—a very good

FIG. 105.—Plain Armature Stamping

FIG. 106.—Armature Stamping, Plain-Toothed

method. The holes are supposed to act as coolers ; but, as a matter of fact, these small holes have no cooling effect whatever. Fig. 108 is a large type of stamping, with four key-ways and eight holes, the

FIG. 107.—Armature Stamping, with Overhanging Teeth

FIG. 108.—Large Plain Armature Stamping, with Four Key-ways

purpose of which is not very obvious ; they are too small to be of any good as coolers. Fig. 109 represents a stamping in which the holes are large enough to act effectually as coolers.

Armature Cores

When armatures are of diameters over three feet they must be built up of segments dovetailed into a steel or iron rim of a wheel. Fig. 110 represents a segment for this purpose with two dovetail keys.

FIG. 109.—Wheel Stamping

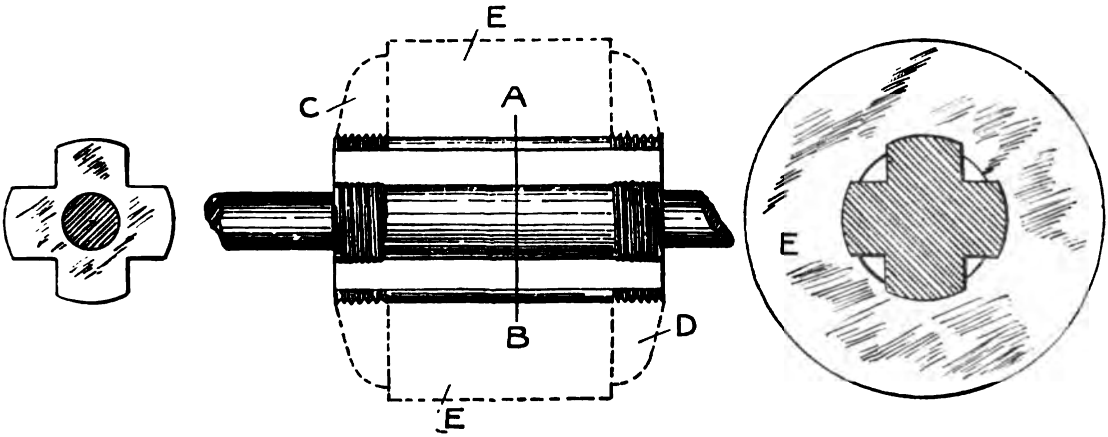
The stampings are insulated from each other by very thin paper or varnish, and are generally clamped up on the shaft by screws and washers. A very good plan is to slot out four broad key-ways on the shaft, and cut screw threads on the feathers to fit large nuts, Fig. 111; the stampings then have four key-ways to fit. By this means a very firm and solid job can be made.

FIG. 110.—A Segment of Armature Stamping

The winding of the coils is carried out either by hand on the armature, or by coils made in a former, Fig. 112, and then laid in place or with solid bar end connected.

Fig. 113 represents a B.T.H. motor armature ready for winding, the smooth-end portions are provided for laying on the former-wound coils. Fig. 114 shows the coils in process of laying on; and Fig. 115 the completed armature.

The "former" system of winding is better illustrated in the dia-



End View of Shaft

Armature and Shaft

Section through A B

FIG. 111

gram, Fig. 116, a thirty-two slot armature; the coils are placed on the core, as shown for a four-pole field magnet; the coils must be so

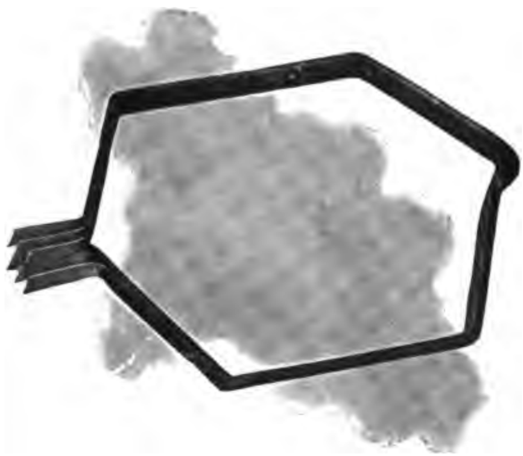


FIG. 112.—Former-Wound Coil

shaped that they have a short and long side, so that all the long sides form top layers and the short sides bottom layers in the slots. Beginning, then, with a short side, we place it in the bottom of slot 9, and its long side over slot 1, that is, with a span of eight slots. We now go on adding coils until we come over slot 9 with a coil,

thus filling slot 9 up, and so on until we come to slot 1 again, but this time with a short side of the coil; the long sides of the first eight coils must be held up in order to pass the short sides of the remaining coils under them and into the bottom of the slots. In this way a perfectly symmetrical winding is obtained.

This same armature is shown in Fig. 117 for the small dynamo

FIG. 113.—Core of Armature for Former Winding

illustrated on sheet, Fig. 119, as calculated out for construction. It is, however, bipolar, so that coils would require to span half the circumference; the large end of the first coil would come over slot 1, and the small end into slot 17, and so on all round until the top of 17 is filled by the last coil, the short end of which is the under half of slot 1.

For this armature to give 110 volts each coil would require to

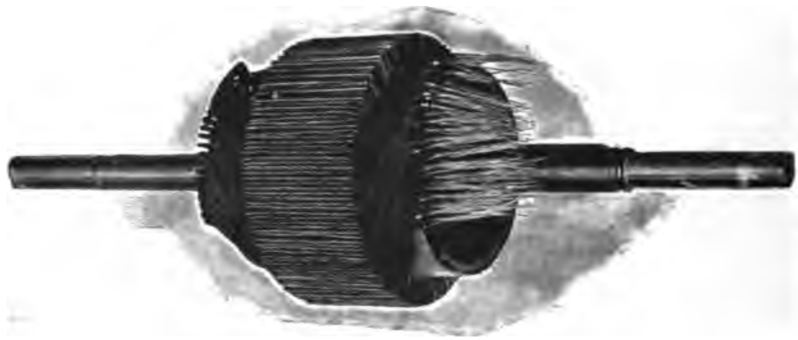


FIG. 114.—Armature Partially Wound

have nine turns of wire, so that the slots when filled would have eighteen wires per slot; the size of wire would be No. 15 S.W.G.; the number of slots = 32, ¼ inch wide, 1⅛ inch deep; the breadth of the stamping part of the armature is 4 inches, with 2 inches of smooth ends for coils to be laid in, as shown in Fig. 118.

The sheet of drawings, Fig. 119, is drawn for the practical

construction of a 1 K.W. dynamo or motor—not a toy, but a sound working motor fit for hard prolonged daily work. The frame consists of a cast-iron casting, as shown in section through E F, with

FIG. 115.—Former-Wound Armature

a cast mild steel magnet bolted on top carrying the top pole-piece N, the bottom pole-piece S being cast with the frame F. One end of the frame has a bearing *b* for the pulley end of the shaft to come through, and the other end of the frame is bored out larger in diameter than the field bore, so that the armature may be withdrawn. The

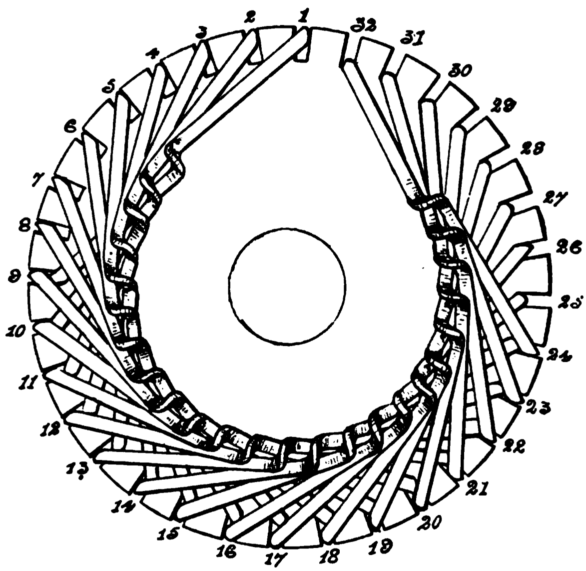


FIG. 116.—Former Winding for Four Poles

bearing at this end is a brass casting fixed by screws in slots, so that the position of the brushes may be adjusted without a special brush rocker; the brushes are carried on spindles in this bearing bar,

as shown in section through A B, and end view F. A complete view of the machine is shown in end view and elevation in Fig. 120.

Two bobbins of field-magnet wire are fitted on the 3¾-inch spaces at A and C in section through E F; these bobbins to be

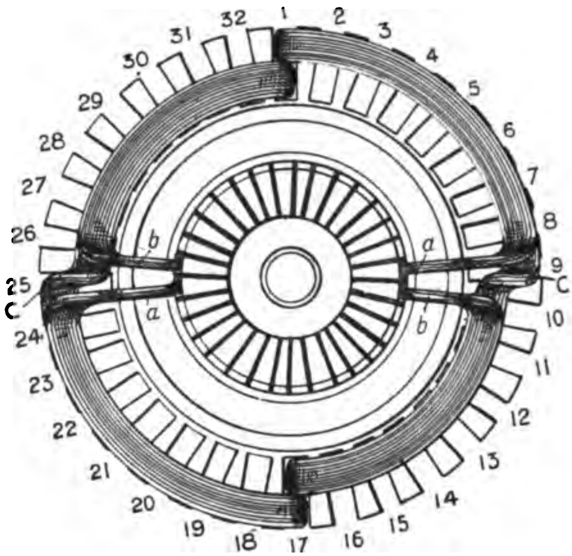


FIG. 117.—Former Winding for Two Poles

filled to a depth of 2¼ inches with No. 20 copper wire, single cotton covered.

There are many types of winding for armatures, but the former-wound coil seems to be the best, and is becoming universal except

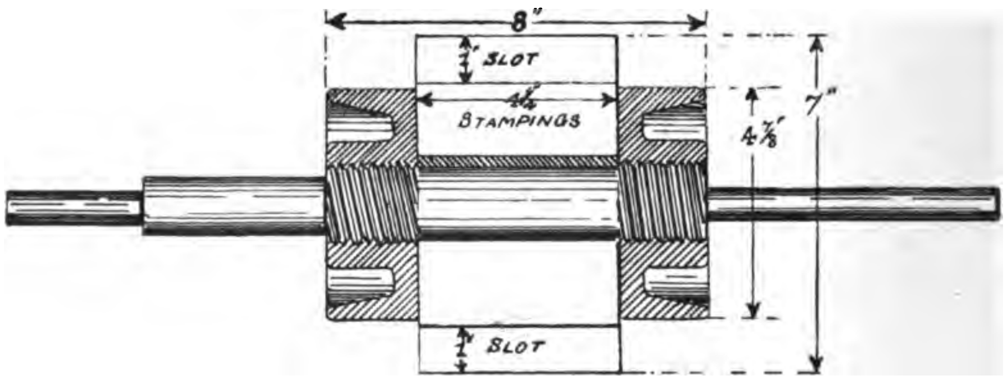


FIG. 118.—1 K.W. Armature and Shaft

for low pressures, in which case bar winding is best if a unipolar machine is not adopted. In Fig. 121 is shown a diagram of Hopkinson's end-connected armature for a six-pole machine, the black connectors being front, and the back ones dotted in; there

Special Design, Simple Dynamo

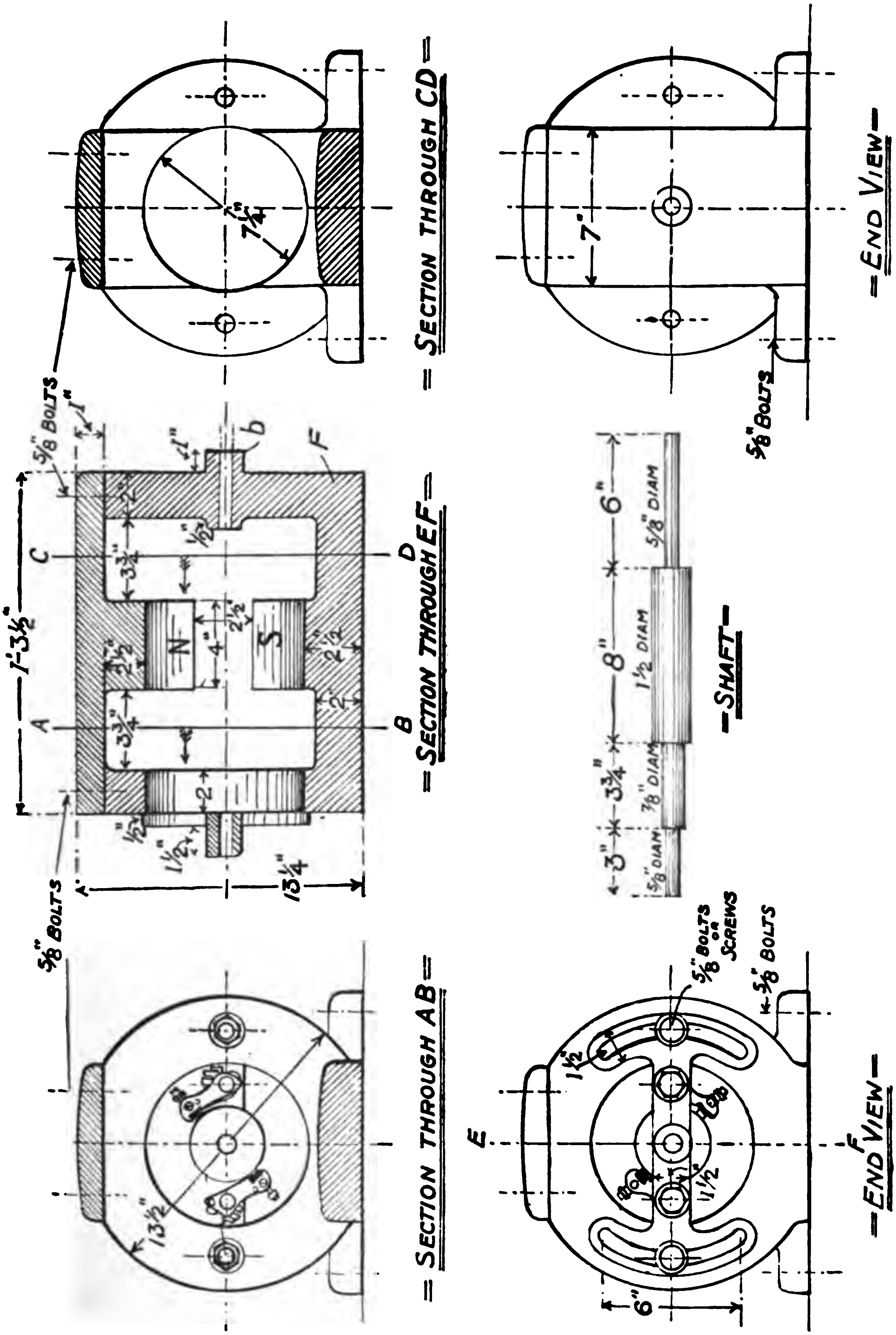


FIG. 119.—Details of 1 K.W. Bi-Polar Dynamo

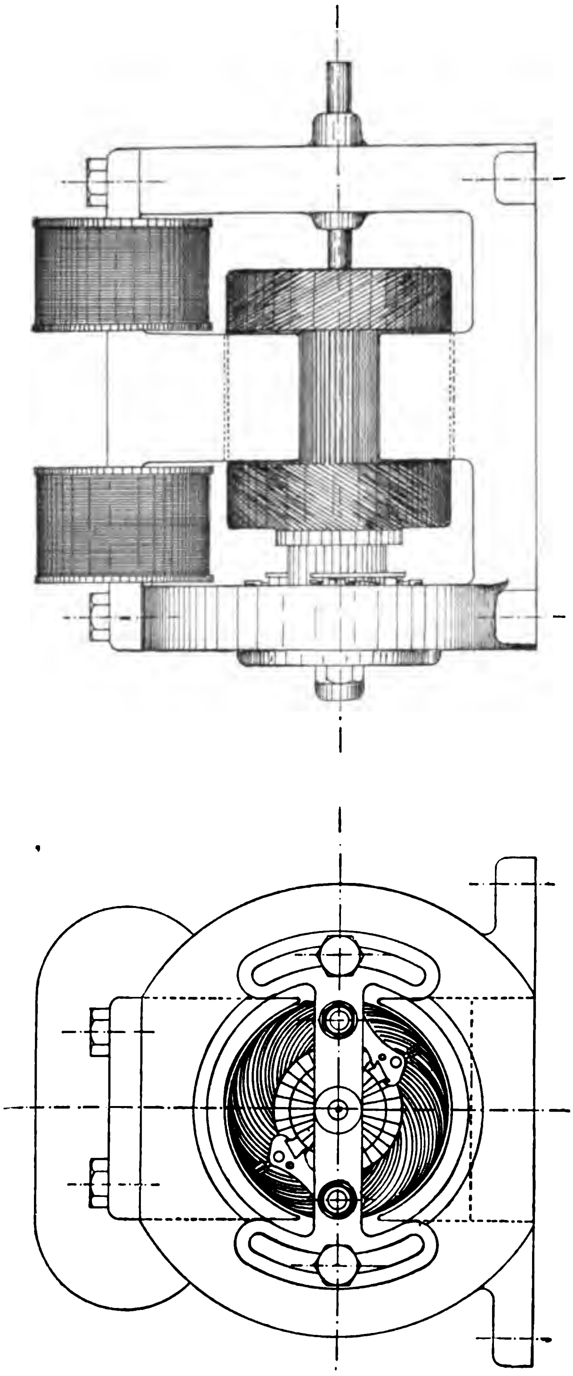


Fig. 120.—1 K.W. Bi-Polar Dynamo Complete

being twenty-eight bars, that is, two less than a multiple of six, a parallel armature.

Another end-connected diagram is shown in Fig. 122 for four poles, a series winding for two sets of brushes at right angles.

Another winding is shown in Fig. 123 for four poles for continuous-current dynamos and motors, and refers to a particular disposition of the commutator brushes, one of the objects being to reduce sparking. The armature is provided with an even number of conductors, not a multiple of the number of poles. Fig. 123 illustrates the invention applied to a four-pole machine. In this case there are fourteen conductors, which are connected together and to the segments of a seven-part commutator in the manner shown. Upon the commutator bear four brushes d^1, d^2, d^3, d^4, of which opposite brushes d^1 and d^3 or d^2 and d^4 are at the same potential and supply current alternately

Fig. 124 shows a method of winding armatures for large currents in order to avoid heating and sparking.

Drum Windings

The conducting-bars A of a drum armature for a bi-polar dynamo are each divided into 2, 3, or n sections, and the resulting number increased or diminished by 2, 4, or $2n - 2$, each section being connected not to the one opposite to it, but to the 2nd, 3rd, or nth before that, through commutator segments C, of which there are half as many as there are sections in the armature and on 2, 3, or n of which bears each of the brushes B, B^1. In the example 12 bars are each divided into three sections and four subtracted, the result being 32 sections. These are connected together through 16 commutator segments in the manner shown. In the case of a multipolar dynamo having 4, 6, or $2m$ poles, the number of sections obtained in the manner above described is multiplied by half the number of poles, and each section connected not to the one which is $\frac{1}{4}$th, $\frac{1}{6}$th, or $\frac{1}{2m}$th of the circumference round, but to the 2nd, 3d, or nth bar before that. The number of brushes is equal to the number of poles. In applying the invention to a ring armature each conductor is divided into 2, 3, or n sections, and the resulting number increased or

FIG. 121.—Hopkinson's Winding

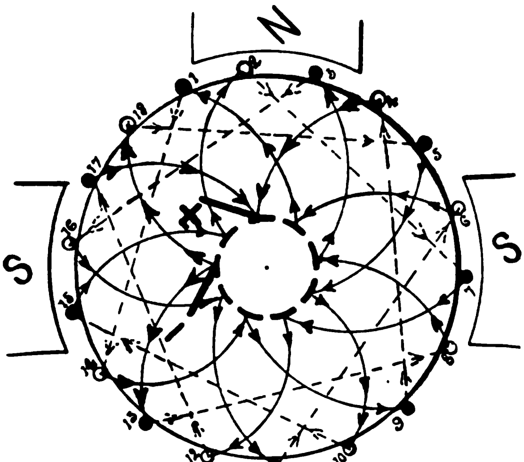


FIG. 122.—Four-Pole Series Winding with Two Brushes

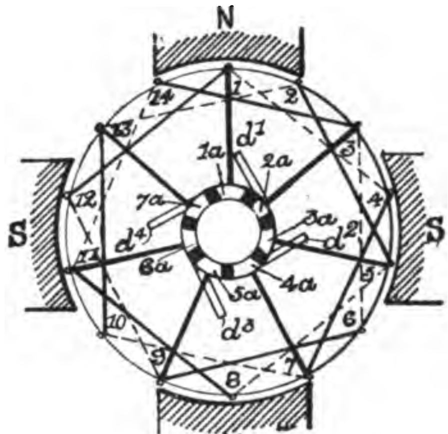


FIG. 123.—Four-Pole Series Winding with Four Brushes

diminished by 1, each section being connected to the 2nd, 3rd, or nth in advance through a commutator segment, of which there are as many as there are sections in the armature.

Drum Windings

The winding of armatures is difficult to teach on paper, while it is exceedingly simple in practice. The great point is to secure good insulation. The winding may be very neat and workmanlike, and yet be defective in insulation. There are great differences between workmen in this respect. The best of insulation materials are weak, easily broken and crushed; and, once the winding is complete, no inspection can detect damaged insulation. It is therefore necessary to supervise the winding very closely.

An idea of end-connectors for low-pressure armatures may be gathered from Fig. 125, an arrangement by Siemens Bros. An arma-

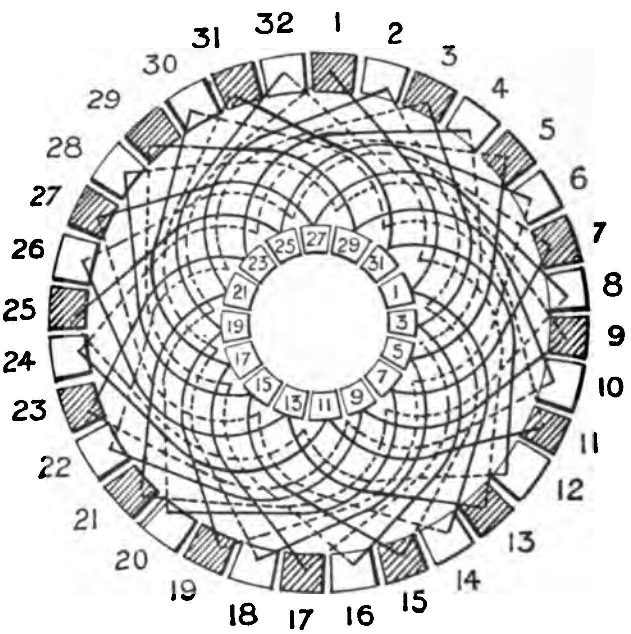
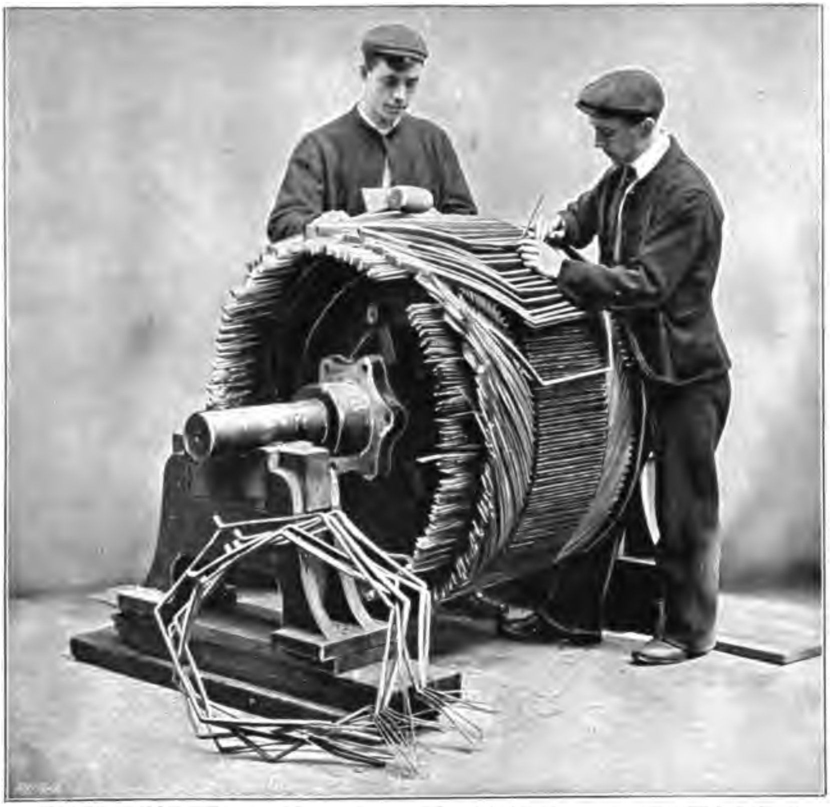


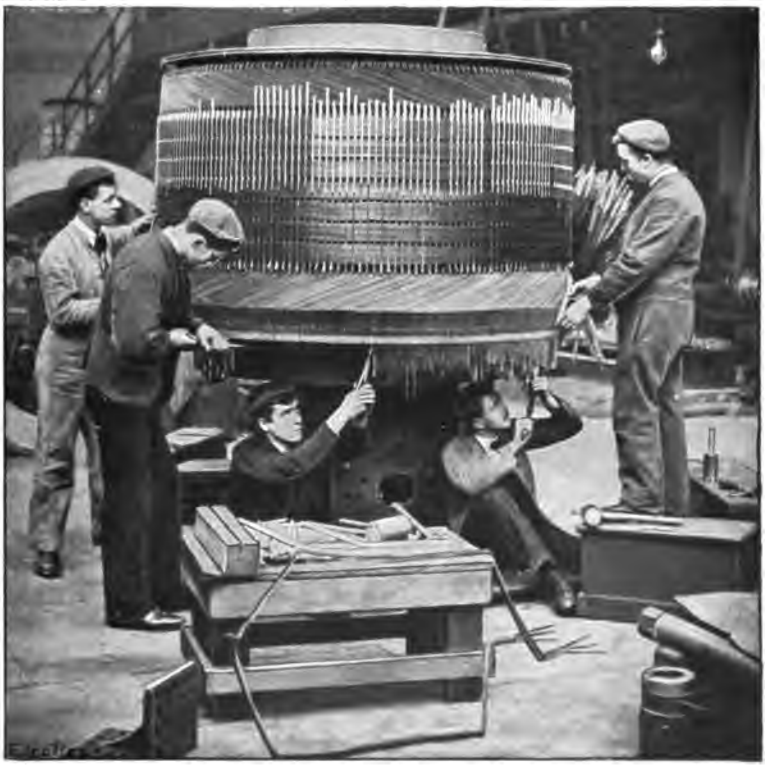
FIG. 124.—End Connections of Bi-Polar Drum

ture for a generator or motor has the sections of its periphery filled with two layers of conducting bars arranged in pairs, lettered A, B and C, D on one side, and A^1, B^1 and C^1, D^1 on the other. The outer pairs A, B and C^1, D^1 are longer than the inner pairs C, D and A^1, B^1, and one bar of each pair is longer than the other. Each outer bar on the one side is connected to an inner bar on the other (for example, A to A^1 and B to B^1), and the longer bar of each outer pair (that is A and C^1) is connected to a plate of the commutator.

It is now necessary to enter more fully into the design and calculation of the details of motors and dynamos. It is a special study in itself to be found in special works, but a few rules will be useful to most installation engineers handling dynamos.

In every case the speed of the machine is fixed, also the





ARMATURE WINDERS AT WORK WITH "FORMER" MADE COILS
MAVOR & COULSON ARMATURES

K.W. output, and the number of turns of wire on the armature can be counted or found out otherwise.

Now if N represents the speed, and N*t* the turns of wire on the armature, and E the working voltage, and W output in watts, C, the current given out, will equal W, and the magnetic flux total will be equal to $Z = \frac{E \times 10^6}{N \times Nt}$. And the greater Z is, and the smaller N*t*, the better the machine as a general rule.

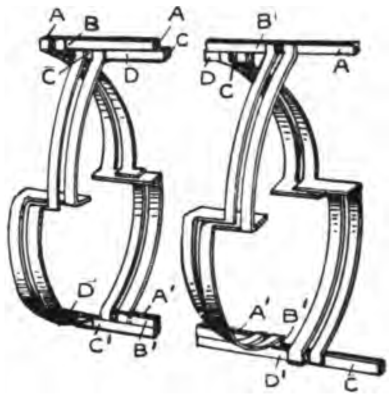


FIG. 125.—Siemens' End Connectors

Take, for instance, a machine for 100 volts in which the speed N = 1000 revolutions per minute, and counting the wires all round the armature as = 320, the Z must equal $\frac{100,000,000}{320 \times 1000} = 312$. Then in this machine Z equals 312 English lines in this case as total flux.

Now, take another machine, same speed, same voltage, in which the wires counted all round the armature amount to 240, then $\frac{100,000,000}{240 \times 1000} = 458$ as Z, this latter would be by far the best machine. The total flux of 458 against 313 would of course require more iron in the magnets, and perhaps a little more exciting power. The reason why the machine with less turns of wire on the armature and more magnetic flux is the best, is obvious from the fact that all the commutator troubles and drop of pressure due to armature current are proportional to the ampere turns on the armature.

If the ampere turns of the armature are greater than a certain proportion to the magnetic flux, then undue heating, sparking, and wearing of the collecting brushes takes place.

Different designs require different treatment. No hard and fast formulæ can be given for designing any kind of machinery, not even dynamos and motors. All that can be done is to lay down general formulæ and rules of experience; and in every case the experienced judgment of the designer is required to guide him in settling the dimensions of details upon which success so much depends. If some rule for arriving at the value of Z for any proposed design can be formulated, then the design of machines would be much simplified. The quantities to be found are Z and N*t* in all designs. We must find one or other of these before any design can be commenced, and, as the performance of the machines depends not only on the actual value of Z, N*t*, but on the proportion they bear to each other, their importance is obvious in any given machine. Z × N*t*

is a constant; if, therefore, we can find the one, the other follows naturally.

In every design the designer has the following data given:—

N = the speed in revolutions per minute.
K.W. = the output.
E = the voltage.
C = the current.

And it is his business to find out what Z and N*t* are to be to give these values in a machine to run highly efficiently and faultlessly; and yet we have no general formulæ by which either of these unknown quantities can be ascertained. I have made some attempts at a solution of the problem as to finding the value of Z the total magnetic flux in the armature, as follows:—

The formula is $Z = \sqrt{K.W.} \times 200$, where Z is the total magnetic flux through the armature in Kapp lines, K.W. the kilowatts output, and 200 a constant which different designers may alter in value according to their skill. The lower it is, the *cheaper* the machine; the higher it is, the *better* the machine.

This formula assumes one speed of 1000 per minute for all machines; to apply it to other speeds we use another factor. For reduced speeds we divide the standard speed of 1000 by the given speed, and then multiply the constant 200 by the square root of the quotient. Thus, if the speed were to be 250, then $\frac{1000}{250} = 4$, hence then the constant instead of 200 would be $200 \times \sqrt{4} = 400$.

Then for higher speeds we divide the given speed by the standard speed, and then divide the constant 200 by the square root of quotient. Thus, for a speed of 4000, instead of 200 the constant would be

$$k = \frac{200}{\sqrt{4}} = 100.$$

Z, then, is found when speed is under 1000,

$$Z = \sqrt{K.W.} \times 200 \times \sqrt{\frac{1000}{n}},$$

and by

$$Z = \sqrt{K.W.} \times 200 \times \frac{1}{\sqrt{\frac{n}{1000}}},$$

when speed is over 1000, *n* being the speed given. Having thus found Z, all the rest follows with ease. Of course, this formula can be written somewhat differently, but it would not be so clear in any other form for my present purpose.

Dynamo Construction Formula

With this formula we have now all the following data for designing any machine :—

K.W. = the output.
n = the speed.
E = the terminal voltage.
Nt = turns of wire or bars on the armature.
Z = total magnetic armature flux.

$$Nt = \frac{E \times 10^6}{Z \times n}.$$

All the rest of the design can now be left to any designer with some experience, and a book of reference tables of iron and copper materials.

It is remarkable how few sparkless machines are to be seen after all the elaborate treatment their design has received by scientific electricians, for, while their mechanical construction and artistic form have vastly improved in ten years, it cannot be said their electrical design is much improved over older machines ; very few designs display any originality.

This formula is an improvement on that suggested in Vol. I., being more general in application.

The formula applies to multipolar and bi-polars alike. In a multipolar with parallel armature circuits Z is the flux from one pole only, and with series-circuit armature winding, Z is the sum of the total flux from all the poles of same sign.

Thus, if for example a 300-K.W. dynamo be calculated, we get

$$\sqrt{300} \times 200 \times \sqrt{\frac{1000}{100}} = 17.32 \times 200 \times 3.3 = 11{,}431$$

English lines, or in round numbers 11,000 = Z.

Then to find Nt,

$$\frac{500 \times 10^6}{11{,}000} = 454 = Nt.$$

If a bi-polar dynamo were used, the magnet limbs would be exceedingly massive for this magnetic flux—nearly 2 feet by 3 feet section.

It would still require a large section of magnet even if we made it four-polar, halving the sections of the limbs of the magnet into two N and two S poles and doubling the Nt, using wire of half section on a parallel-brush armature.

For a four-polar machine we would require to multiply Nt by 2 and divide Z by 2 to arrive at the flux from or between one pair of poles. And similarly for an eight-pole machine, Z would be divided by 4 and Nt multiplied by 4.

The armature wire on a bi-polar or series-circuit multipolar, with only two circuits, has to carry half the current, and in a four-polar parallel armature each circuit carries one-fourth the current, and in an eight-polar one-eighth the current.

Thus I find Z and Nt for every machine, first, as a bi-polar, and then, according to the dimensions, determine whether to make it for six, eight, or any other multipolar.

If the magnets are mild steel, Z divided by 15 will give very nearly the square inch sectional area of the steel limb of a bi-polar required to carry Z. Thus, in our example,

$$\frac{11,000}{15} = 733 \text{ square inches.}$$

Now my own rule is to divide this magnet section into magnets not exceeding 100 square inches sectional area or thereabout; that being so, number of poles $= \frac{733}{100} = 7.33$. This odd number is the nearest to an even one of 6 or 8, which means 6 N poles and 6 S poles, or a 12-pole machine; and 12 poles would be quite satisfactory, each of $\frac{733}{6} = 122$ square-inch section or $12\frac{1}{2}$ inches diameter.

This is for a large, very slow speed, high-pressure machine; the total current is 600 amperes, the armature wires will therefore each have to carry 100 amperes, as there are 6 pairs of poles and 6 circuits.

Now to apply the formula to a moderate size four-pole machine, say, 60 K.W., speed 500, volts 250.

Here we have

$$Z = \sqrt{60} \times 200 \sqrt{\frac{1000}{500}} = 7.74 \times 200 \times 1.41 = 2182,$$

or in round numbers, to save fractions, 2000. Hence,

$$Nt = \frac{250,000,000}{2000 \times 500} = 250,$$

and hence the sectional area of the pole-limb for this flux would be $\frac{2000}{15} = 133$ square inches for a bi-polar and for a four-polar $\frac{133}{2}$, making four poles of 66 square inches each, about 9 inches diameter and we would double the Nt, that is, total turns 500, but of half the cross section of wire required by the bi-polar.

Then take the case of a small bi-polar machine, say 9 K.W., 250 volts, speed 1000.

$$Z = \sqrt{9} \times 200 \times \sqrt{\frac{1000}{1000}} = 600;$$

hence,

$$Nt = \frac{250,000,000}{1000 \times 600} = 417,$$

and the section of the magnet limbs $= \frac{600}{15} = 40$ square inches, or $7\frac{1}{4}$ inches diameter. There is no need to make this a multipolar machine.

In the formulæ the constant multiplier 200 is perhaps a little too low in value, but it gives good results; if 250 is used, still better results may be got.

These calculations show how the leading and most important factors of any dynamo machine are found.

Results of Experience in Construction

We have found out how to determine the armature winding, also the section of the pole limbs. There remains to determine the armature sections and number of slots. I will quote some valuable opinions, tables, figures, and examples of modern practice, given by Mr. F. W. Davis in *The Electrical Review* of London :—

The drum armature possesses the disadvantage that coils having a large difference of potential between them cross one another in the end windings, though this is not of such moment when either a former-winding or a bar-winding is used. For pressures of over 500 volts, the ring armature is the more suitable owing to the greater facilities it offers for the insulation of the coils.

When the type of core has been decided upon, the next question to decide is whether it shall be plain, toothed, or ironclad. The toothed core possesses several important advantages over the plain core, which are enumerated below :—

1. The length of the air-gap may be considerably reduced, and consequently fewer ampere coils will be required on the field-magnet coils. This applies more especially to multipolar machines; for, if the air-gap is reduced to any appreciable extent in a bipolar machine, it becomes impossible to obtain sparkless commutation. It is therefore advisable to use plain cores for the armatures of bipolar machines, and toothed cores for multipolar machines.

2. It offers better mechanical construction; both because of the positive driving afforded to the conductors, and also on account of the actual drag on the conductors being considerably less. *The mechanical drag, in this case, comes mainly on the iron core itself.*

3. There is almost an entire absence of eddy currents in the conductors, even when solid bars are used, owing to their being in a very weak magnetic field.

The following table, which gives the maximum nett length of core in terms of the virtual diameter which it is advisable to use, will serve as a guide in this matter :—

No. of magnet poles.	Maximum permissible nett length for drum armatures.	Maximum permissible length for ring armatures.
2	2 diameters (virtual).	1. diameter (virtual).
4	1 diameter "	.5 " "
6	.6 " "	.3 " "
8	.5 " "	.25 " "

The actual dimensions of the core can now be determined. This may be done, in the first instance, by means of one of the

formulæ given below. After getting the size of the core (approximately) by this means, its length can then be altered in accordance with what the later calculations show to be necessary. (Compare this with my process.)

$$\text{For dynamos: } l\,(d-d_1)^2 = \frac{\text{output in watts}}{\text{r.p.m.} \times \text{number of poles} \times k}$$

$$\text{For motors: } l\,(d-d_1)^2 = \frac{\text{output in B.H.P.}}{\text{r.p.m.} \times \text{number of poles} \times k}$$

l = net length of iron in armature; d = virtual external diameter of core; d_1 = virtual internal diameter of core; and k is a constant, the values of which are as follows:—

	Drum armatures.	Ring armatures.	
k =	.020000	.052000	for dynamos.
	.000027	.000070	for open-type motors.
	.000021	.000056	for protected-type motors.
	.000018	.000047	for enclosed-type motors.

These formulæ, which are applicable to machines having any number of poles, give a good idea of the size of armature core

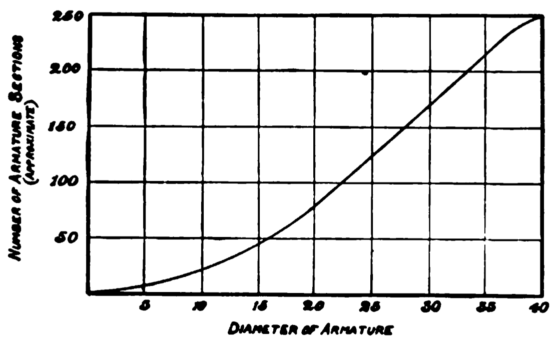


FIG. 126

(consistent with good commutation and cool running) which is necessary for any machine of a given output.

If the armature core is to be of the toothed type, we must now consider the design of the teeth—a more important matter, by the way, than it is generally considered to be. There are several points that merit attention when deciding upon the proportions of the teeth. The first dimension that we require is the length of the teeth. In order to allow ample room for the conductors, the slots (or perforations, if the disc is of the ironclad type) should be about .125 $(d - d_1)$ in radial depth (d being the virtual external

diameter of the core, and d_1 the virtual internal diameter, as before). This agrees well with good average practice, and it is neither necessary nor expedient to make them much deeper than this. The number of teeth on the core is usually the same as the number of sections in the armature, and should be such that the total number of conductors can be divided up so as to get an equal number of conductors in each section. A rough idea as to the number of sections suitable for a given armature may be obtained from the curve shown in Fig. 126. It remains now to determine the relative width of the teeth and the slots. Here it will be well to enumerate some of the advantages and disadvantages of wide *versus* narrow teeth. It is assumed, of course, that the sides of the slots will be parallel, as shown in Figs. 127 and 128. The wider the teeth and the narrower the slots, the greater will be the mechanical strength of the teeth, and the less the hysteresis and eddy current

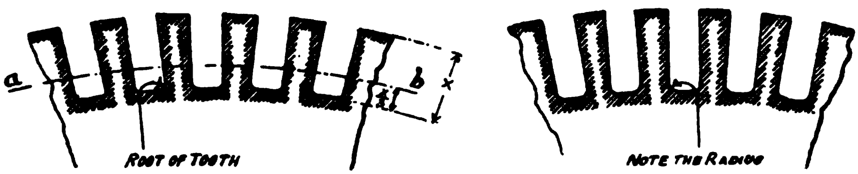


FIG. 127 FIG. 128

Armature Teeth

losses in them. The less, too, will be the mechanical drag on the conductors.

The width of the slot at the circumference of the core should never exceed 1.5 times the length of one of the air-gaps; otherwise the eddy-currents induced in the magnet poles by the movement of the teeth will cause an appreciable loss of power, with heating of the pole-pieces. The teeth are sometimes made to overhangthe slots at the circumference (Fig. 127), but this is not advantageous, as it increases the self-induction of the coils, and is a very undesirable feature if former-winding is to be used. It is a good plan to have the corners of the slots filled in with a small radius at the bottom, as shown in detail in Fig. 128. This increases the section of the iron in the teeth where it is most needed, and reduces the hysteresis and eddy-current losses, besides imparting mechanical strength. Some manufacturers, instead of having the slots punched in the core discs before assembling them, prefer to assemble them on the spider or shaft first, and then mill out the slots afterwards. This is not to be recommended, as the teeth cannot then be relied upon for being of uniform thickness. Moreover, this method necessitates dismounting the stampings afterwards to take off the burrs caused by the milling.

Most makers seem to be agreed as to the best thickness for discs

of a given diameter. The thicknesses of disc which generally obtain in modern practice are tabulated below :—

Virtual diameter of discs.	Thickness of discs.
Up to 30 in.	025 in.
From 30 in. to 48 in.	.03125 in.
From 48 in. to 60 in.	.0375 in.

The magnetic induction is a quantity that varies but slightly in the machines by different makers. The mean average induction in the teeth will be somewhere between 100,000 and 130,000 C.G.S. lines per square inch, the heavier inductions being used most in generators and motors for electric traction. The induction and permeability of the teeth at one-third of the distance up from the roots (see Fig. 127) may be taken as a close approximation to the mean average induction and permeability. If the magnetic inductions are much lower than those given above, the field magnet will not be powerful enough relatively to the armature. If, on the other hand, the inductions are much higher than the maximum values given above, there will be undue losses in the core, causing heating and reducing the efficiency of the machine.

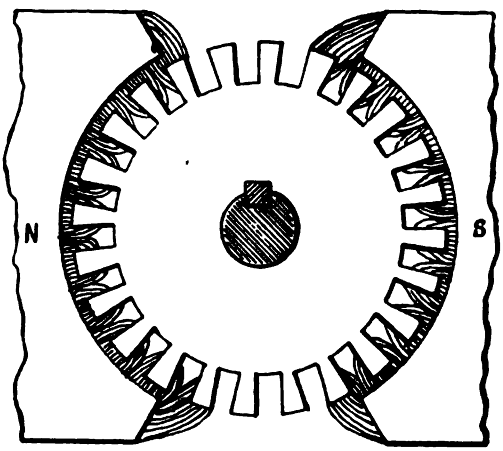


FIG. 129.—Diagram showing Magnetic Fringe at Teeth of Armature

For multipolar machines the induction in the armature core and teeth should be slightly lower than in bipolar machines; in fact, it may be taken as a general rule that the greater the number of magnet poles the lower should be the induction in the armature core. With regard to the induction in the air-gap, it is important to remember, when dealing with toothed cores, that there is a magnetic fringe at the side of each tooth as shown diagrammatically in Fig. 129, which makes the effective area of the air-gap greater than it would otherwise be. This fringe virtually increases the area of the air-gap by an amount equal to the product of the length of the polar face (measured parallel to the shaft) and the length of the air-gap for each tooth under the pole. This is correct where the air-gap is less than the width of the slot at the circumference of the core; where it is equal to, or greater than, the width of the slot, the area of the air-gap is reckoned as if the armature core were a plain one. The increase in the effective area of the air-gap, due to the magnetic

fringing of the teeth, is generally considerable, and it should therefore be carefully taken into account.

The preference is towards short armatures of large diameter, and I think the best plan is to adopt a rule for length something like this: If the cores of the field magnets are circular, as in good practice they usually are, then the length of the armature core should be about 20 per cent., at most, greater than the diameter of the field cores.

The length of field-magnet cores is determined principally from the wire coil required for exciting. This coil must be provided for in length and thickness. Length adds no power to an electro-magnet, so that they are made as short as possible—only long enough to accommodate the number of turns of wire required in the exciting coil.

The importance of the design of cheap small motors is overlooked. Most designers have been too obviously copying common designs without regard to expense. A first-class motor need not be a slavish copy of some other motor, especially in small sizes, and only small motors can be used in factories for transmitting power, as it is only by getting rid of all shafts, belts, and gearing that electrical driving of machinery shows its superiority.

A power-distribution plant in most factories should provide a three-wire system if motors are over 5 horse-power, and down to $\frac{1}{4}$ horse-power. I have had an installation put up in which sixty-five motors, varying from $\frac{1}{12}$ horse-power to 15 horse-power, in one factory, one motor to each machine, coupled as direct as possible. To properly deal with such an installation it is necessary to have 100 volts for motors, under say 3 horse-power (and these are the great majority), and 200 volts for those above 3 horse-power.

Small motors wound for high voltage are expensive and nasty to work with.

In the future, when electricity may be delivered in bulk at the factory door, it will be found better to receive it on a rotary transformer, and transform it there to the pressure and current best suited to the motors.

This is the great drawback to the use of motors on muncipal supplies: 200 to 250 volts are all right for lighting purposes, but certainly far too high for small motors under 3 horse-power. Small motors, as may be seen from two makers' lists now before me, professing to make small motors a speciality, are costly. As a motor is not a complete motor without a proper starting switch, the cost of a cheap but good one is included. The motors are 1 horse-power speed, 1300; volts 110; prices, No. 1, £22, 16s.; No. 2, £28. Now, no 1 horse-power motor is worth £28. In many cases the motor would cost more than the machine it drives. There is therefore considerable probability that a well-equipped factory, making a sound motor of small size, cheap design, efficient and safe, would meet with considerable success.

It is interesting to note the parts in the dissected continuous-current dynamo or motor of medium size, and of the at present fashionable type, as shown in Fig. 130.

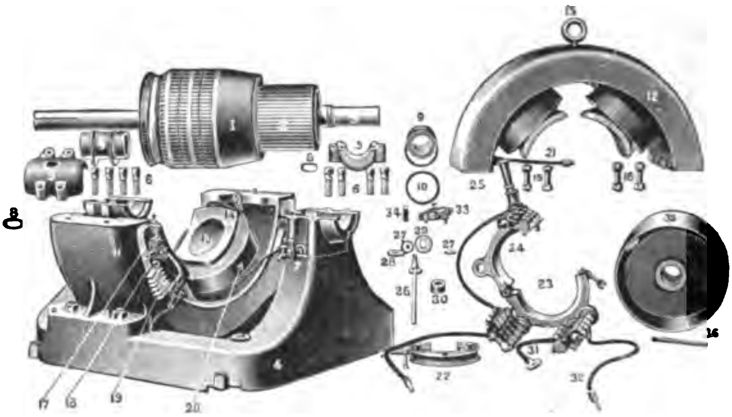


FIG. 130.—Details of Continuous-Current Generator

1. Armature (includes 2 and 3); 2. Commutator; 3. Shaft; 4. Base; 5. Bearing Cap; 6. Bearing-Cap Screws; 7. Oil Cock; 8. Oil-Hole Cover; 9. Journal Box; 10. Oil Ring; 11. Lower Magnet Frame (includes 13 and 14); 12. Upper Magnet Frame (includes 13 and 14); 13. Pole; 14. Pole Shoe; 15. Eye Bolt; 16. Magnet Frame Bolts; 17. Terminal Board; 18. Terminal Block; 19. Compounding Rectifier; 20. Field Coil; 21. Field Cable; 22. Rocker Seat with Screws; 23. Brush Rigging (includes 24, 25, 26, 27, 28, 29, 30, 31, 32, and 33); 24. Rocker (includes 25); 25. Rocker Handle; 26. Brush Stud; 27. Brush Stud Nut; 28. Brush Stud Insulating Washer (Round Hole); 29. Brush Stud Insulating Washer (Oval Hole); 30. Brush Stud Insulating Sleeve; 31. Brush Stud Cable; 32. Armature Cable; 33. Brush Holder; 34. Brush; 35. Pulley; 36. Pulley Key.

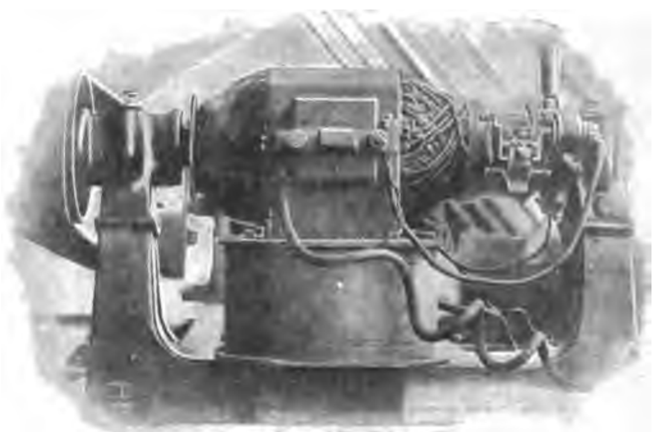


FIG. 131.—Old-Style Drum Armature Dynamo

Fig. 131 represents the old-fashioned drum winding of motors very well; the great bundle of wires crossing and recrossing at both ends forming a perfect maze to the uninitiated. It will hardly be believed at this date that for about fifteen years this primitive style of winding

was practised, the "former" style of winding being first introduced by Eickmeyer some time about 1890, but not generally adopted until about 1898. It is not to be wondered at that alternating systems made much more progress than continuous currents, for the continuous-current machine was considerably neglected, while alternating machinery, being novel, received great attention during that time.

It is the universal idea that alternating machinery alone is practicable for distributing large quantities of electrical energy, the supply being sent out in bulk at 20,000 volts or thereabout, in two or three currents of different phases, to be afterwards converted to usable pressures and continuous current. This system, as we shall see, requires a considerable number of step-up, step-down, and rotary conversions. But continuous currents can be generated and handled at high pressures with the present-day knowledge and experience, so that it is somewhat rash to jump to the conclusion that Polyphase machinery must be preferable to continuous-current plant for large works. It is therefore of interest to refer to continuous-current high-pressure machines actually at work in a new installation.

A most interesting installation has recently been completed by the Rhône Power Company, of Lausanne, which acquired from the Canton of Valais the right to utilise the water-power of the Rhône near St. Maurice. The full power which can be utilised is about 15,000 B.H.P.; of this at present 5000 B.H.P. is in use, and being transmitted on the Thury direct-current system to the town of Lausanne at a pressure of 22,000 volts.

The dynamos are six-pole constant-current machines, giving 150 amperes at 2250 volts at 300 revolutions per minute, and ten machines in series give 22,500 volts.

At the receiving station the continuous current drives continuous-current motors also in series, and these motors drive three phase generators, producing current to be distributed for power and light in the town. Thus we have a practical illustration in which the generally accepted conditions are entirely reversed, the energy being transmitted by continuous current and distributed by alternating current, thus carrying the war into the enemy's country with a vengeance!

When we consider that one ampere would carry about 30 horse-power at 22,500 volts, it is obvious that the transmission can be effected with very small copper conductors with very little loss. But that is not the whole question. It may turn out to be cheaper and better in the end to use continuous currents even with greater losses in the line wires, when we sum up the cost of the convertors and their losses in the alternating system, so that the last word has not yet been said in the old controversy—alternating *v.* continuous current.

There is nothing very special about the Thury dynamo, except perhaps its excellent design and high insulation. There are special regulators and other details, to which reference will be made when we come to consider systems of electrical distribution.

The constant-current series dynamo is generally very well known, being the most common arc-lighting machine in the past.

The series machine depends primarily for its regulating qualities to the armature reaction on the field magnet. With this end in view the cores of the field magnet must be made of much smaller cross section than in constant-pressure machines, so that no increase of current in the exciting coils can increase the magnetic flux. The

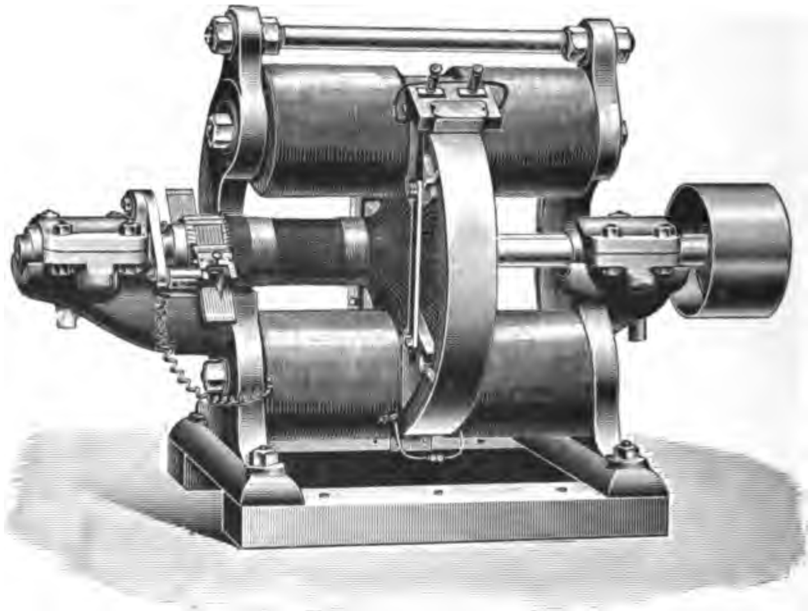


FIG. 132.—Early Schuckert High-Pressure Machine

armature core, on the other hand, must be ample in section, so that an increase of current increases its magnetic effect, and acting against the field, weakens the flux through the armature. This applies to self-exciting series machines. But in separately excited machines, the field cores and coils may be the same as in constant-pressure machines, and thereby considerable advantage obtained, not the least being the increased safety from earth contacts.

With the exception of the old Schuckert arc-lighting machine, the first series dynamos were open-coil machines—Brush and Thomson Houston, too well known to require description. The Schuckert arc dynamo was capable of running up to 1000 volts, when fitted with new types of mica insulated commutator, and the

insulation made on modern principles and with modern materials. It is shown in Fig. 133. The armature is a disc, made by coiling up iron strip on the rim of a narrow pulley; the winding was plain gramme ring winding. It could be short-circuited without damage, the armature overpowering the field where the current exceeded 7 or 8 amperes. This flat type of armature has more armature-reacting properties than any other form of closed-coil armature, hence its importance in series dynamos.

Another early worker in continuous-current transmission machinery was M. Marcel Deprez, an immortal pioneer in this line. In 1882 he made a practical attempt to transmit 10 horse-power over 35 miles of ordinary telegraph wire, the resistance being 950 ohms. The voltage at the generator was about 13,000, current about 1 ampere at most, the efficiency about 25 per cent.; but, as was usual in those days, a series of accidents prevented the complete testing of the installation, ending in the generator being

FIG. 133.—Armature for 75-Light Direct-Current Arc Machine

burnt out by self-induced pressure, due to one of the motor brushes falling out. The next most important transmission of power tests was made between Grenoble and Vizille, 8½ miles' distance; 3000 volts were used and 7 horse-power transmitted. Deprez's dynamos and motors were all closed-coil machines, some of them running up to 7000 volts with two armatures in series; they were separately excited. It is worthy of note that Deprez invented an automatic quick-acting cut-out in connection with his system.

It would present no difficulty nowadays to transmit continuous current between generator and motor generator at 20,000 volts and 100 amperes or more over any distance required in this country, and thus obtain a 250 to 500 volts' supply with only one or two conversions, so that those interested financially and otherwise in electricity supply in bulk might with advantage consider this direct system among others.

The Westinghouse arc-light machine is an open-coil machine,

with a separately excited field magnet. The construction is modern, and therefore much better results are obtained than those from the old machines. It has long been recognised that the open-coil generator, with its pulsating form of current, is particularly well adapted for arc lighting, as the pulsating effect, while giving a steady mean value to the current, causes a very slight but constant vibration in the mechanism of the lamps, thereby reducing to the minimum the chance of sticking, or failure to feed. A decided novelty has been here introduced by using a two-phase armature, the current of

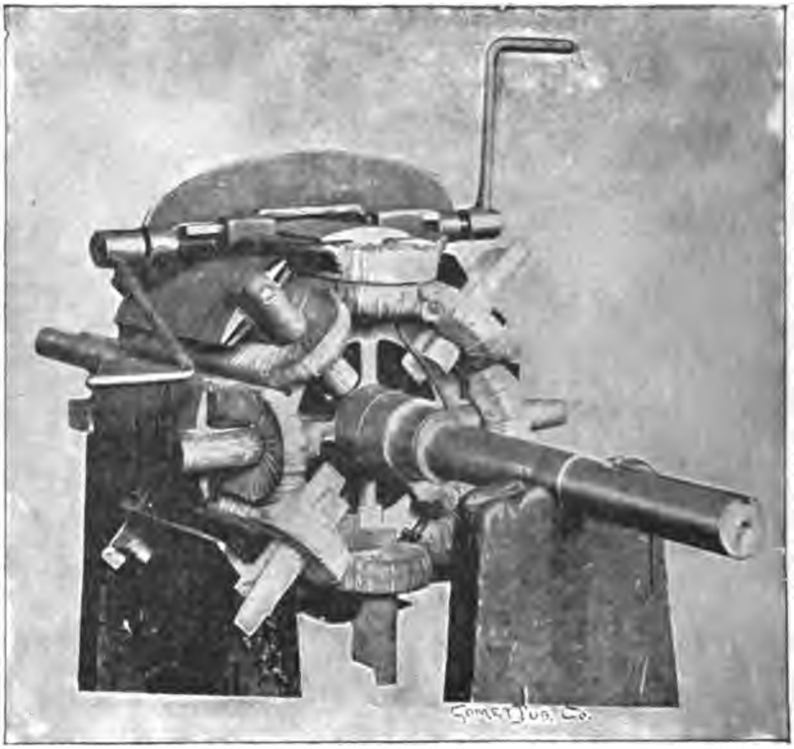


FIG. 134.—Westinghouse Co.'s Method of Mounting Coils on Armature Core

course being commutated. The resulting direct current is adapted to all forms of series arc lamps in use.

The armature (Fig. 134) is made of high-grade laminated steel sheets, punched with "T"-shaped teeth around the periphery. The armature coils are wound on moulds with great care, are thoroughly insulated, and tested independently. Afterwards they are mounted on the armature teeth, where they are held in place by wooden wedges, dovetailed in. There are absolutely no wires on the outside of the armature, consequently it may be handled, or even rolled upon the floor, without fear of damage to the winding. In case it becomes

necessary to replace a coil, the operation can be performed by an ordinary mechanic or dynamo tender in a very short space of time, the old coil being removed and the new one sprung into place in practically the same time it would take to remove the armature from the field of its machine and replace it by a "spare." It is not, therefore, necessary to carry in stock a spare armature for the arc generator. A few armature coils, which cost but little, answer every purpose. A view showing the method of mounting the coils upon the armature core is shown in Fig. 134. They are constructed up to 3000 volts and 8 amperes output. What their efficiency as

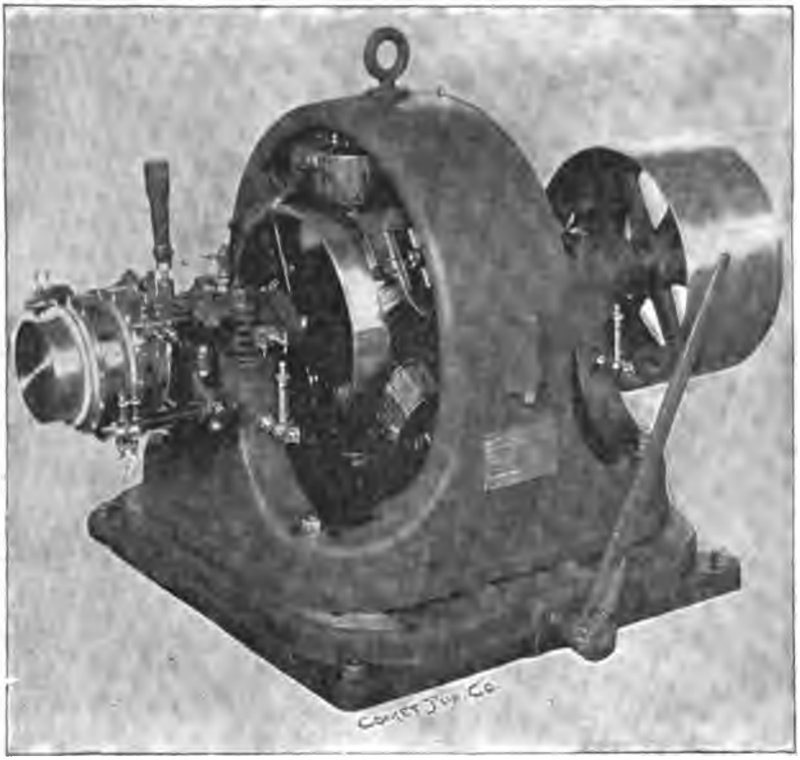


FIG. 135.—Westinghouse Arc Light Machine

transmitters of power is, is not known. They are used for series arc lighting. Fig. 135 shows the complete machine.

In concluding this notice of transmission by continuous currents, it is interesting to recall the fact that Lord Kelvin proposed to transmit current at high pressure to storage cells charged in series and discharged in series multiple, an ideally simple system for supplying electricity in bulk from a distance. There are many difficulties with it in practice, mainly the difficulty of insulating cells.

This, however, could be surmounted by special construction of the battery-house and stands for the cells, with means provided for carrying off acid spray or preventing its rising. A system like this is one of the future.

Next to the armature of a continuous-current generator the commutator plays the most important part. In early days it was a continual source of trouble, and did more to keep back the progress of the continuous-current system than anything else, and gave the alternating system an easy start.

It was called upon to do more than its duty, being attached to badly designed field magnets and armatures. An armature with wire sections, few in number and revolving in a weak field, played havoc with commutators, especially when the armature sections were made up of many turns of wire. The first improvements were made by making the armature windings in sections of only one turn and many sections. Then came another improvement, in increasing the power of field magnets in proportion to the output of the machine. The sparking and destruction of commutators then became much less or disappeared altogether. That is the whole philosophy of sparkless commutation together with proper air space and pole-pieces.

The commutators themselves are expensive affairs, and require the best of materials and workmanship. They are made of blades of hard-drawn copper, as a rule, with mica insulation plates between, and dovetail clamping plates at the ends insulated also by mica.

Various methods of clamping up the plates by the end rings are shown in the figures. Fig. 136 shows one method, a very acute angle in the dovetailing, and elaborate fixing at the end by nuts and washers.

Fig. 137 illustrates another design, in which the sleeve is screwed in the middle and two conical rings forced into the insulation at the ends; and Fig. 138 illustrates another form, with one long end screw and one ring movable. Fig. 139 shows a very common type. All these are suitable only for small commutators.

For large commutators, and even for small ones, bolts and nuts are better for drawing up the end plates, no sleeve being required at all nor washers. This method is shown in Fig. 140. For a given length of brush surface it requires less length of shaft to accommodate it.

The insulation at the ends should not be thick. Some makers use heavy insulation, with the result that it works loose, due to the expansion and contraction by heating of the metal parts. A thin insulation of highest quality is required. All commutators should, after heating and cooling several times, be then tested with a hammer having a leaden head, for loose sections; if such are found

it is evident the end insulation is yielding, and, unless remedied, trouble with that commutator will ensue.

The proper connection of the sections to the commutator plates is also an important matter. Good soft soldering, when skilfully done and of sufficient size at the joint, leaves nothing to be desired; it, however, requires much care and skill, good materials, and great cleanliness about the joints, before applying the solder.

Fig. 141 is a group of Crocker-Wheeler commutators for multipolar dynamos, from the smallest to the largest standard series. The bodies are cast-iron, the blades copper stampings with the slots for receiving the wires cut in projecting legs, forming a flange as shown. We do not follow this practice here. We prefer to form

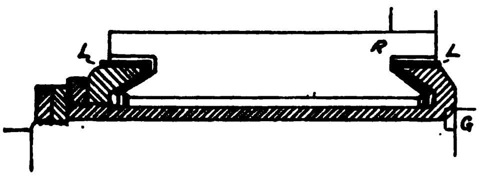
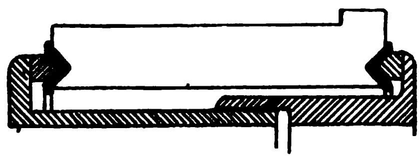
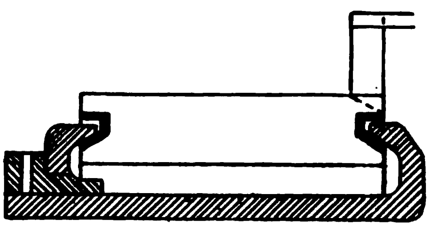


FIG. 136



"Kapp"
FIG. 137



"Kapp"
FIG. 138

"Hopkinson"
FIG. 139

Various Forms of Commutators

the slots in one end of the straight bar, cutting out an anular groove all round, as shown in Fig. 140, page 146, the reason for this preference being that high-class, accurately straight drawn copper bars can be readily obtained of any section and high quality of copper, Messrs. Thomas Bolton & Sons making a speciality of this material.

Stampings are as good, but if any deviation from standards are required, and they often are, then drawn rods of the proper section are better.

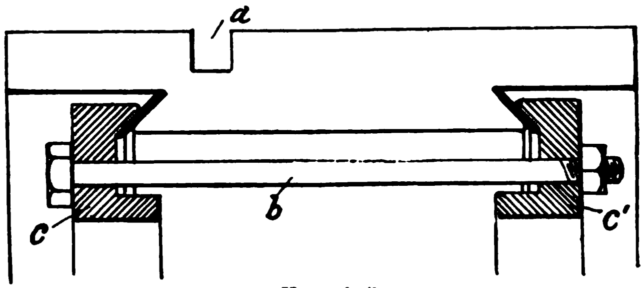
The series and parallel, high-pressure continuous-current machinery has fallen into neglect on account of the fascinating novelty of the alternating polyphase system, and the powerful hands into which the direction of polyphase and alternating work has fallen.

On the score of economy the high-pressure continuous current has by far the best of it, also in simplicity and less first cost.

Commutators

There is a superstition lingering in the minds of many engineers that high-pressure continuous current is dangerous and difficult to manage, but it cannot be more so than an alternating current of same pressure. As before pointed out in regard to electric lighting, the alternating systems had a very great advantage fifteen years ago, when only small customers had to be supplied few and far between, and the highest pressures were 110 volts on lamps; but, under present-day conditions, these advantages have disappeared.

Much the same applies to power work with alternating current. So long as it was on a small scale it had the advantage; but when one comes to a close consideration of some of the bigger schemes recently carried out in this country by foreign engineers' advice, it becomes pretty evident that some schemes are proposed and carried out mostly with a view of installing novel convertors and other



" Kennedy "
FIG. 140.—Commutator for Large Machine

machinery as advertisements, the only excuse for their presence at all being that they were considered necessary by the consulting engineer.

This fashionable system consists of three-phase high-pressure alternating-current generators, with exciters.

Transmission lines to sub-stations at high pressure.

Stationary convertors to reduce the high pressure to 600 or 700 volts fit for

The rotary convertors, from which the energy is finally delivered to a tramway or other system. All this complication against only two similar machines in the continuous-current system with only one conversion.

For instance, at Dublin this alternating system is in use, the tramway pressure being 500 continuous, and the alternating pressure 3500 volts.

But the Dublin or any other system could very well be run without any alternating currents at all, quite as safely and much more economically by continuous current alone.

3500-volt continuous-current generators and motor generators present no difficulties whatever at this date—in fact, never did, even twenty years ago—and a continuous-current system could be de-

signed to give better results than nine out of ten of the polyphase schemes, only it would not exploit polyphase machinery.

But nobody for years has taken the least interest in these things. We have retired before the invasion, and, with eyes shut, humbly accept *ex-parte* engineers' dictation in all important installations. The craze for alternating current and transformers never broke out severely here. And it is to be hoped that all systems should be

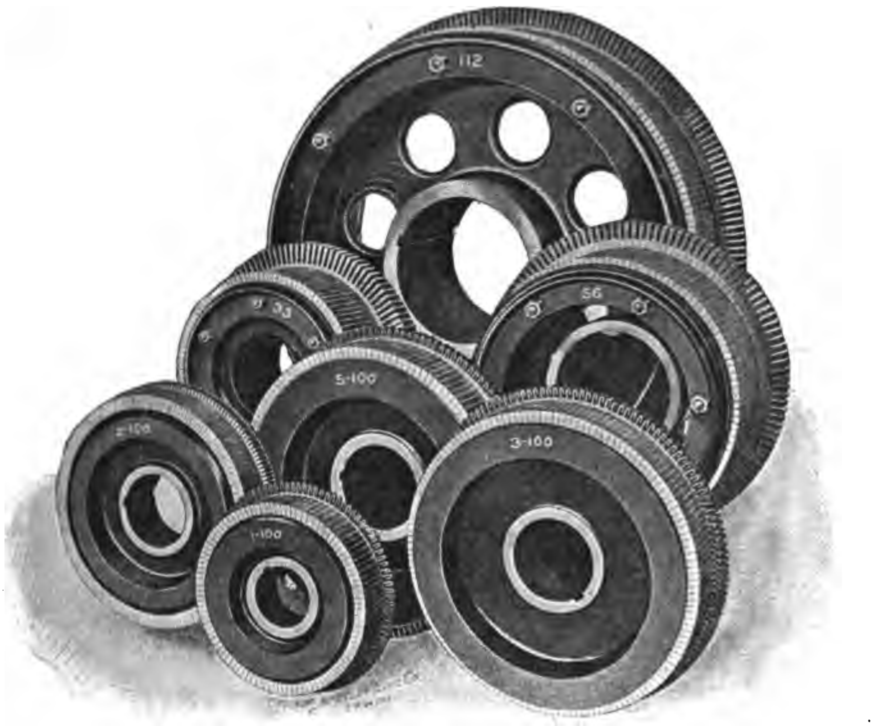


FIG. 141.—Group of Commutators for Multipolar Continuous Current Dynamos

carefully considered, even although at the moment they may not be fashionable among foreigners or at home.

In Vols. I. and II. alternating machinery has been discussed pretty fully, and, as pointed out therein, the field of usefulness for alternating machinery lies mostly beyond ordinary practice in installation work. It comes rather under the engineer of the great railway and distribution schemes, and, just at this moment, it is doubtful whether even in these large schemes it will hold its own. Owing to want of confidence in electrical engineering in this country, and consequent scarcity of capital to develop British ideas, we were in a state of stagnation from 1888 to 1898, a ten years' period during which absolutely no progress

was made. Meanwhile the foreigners were strenuously applying themselves to the perfection and construction of electrical machinery of latest types; so that, when the demand for large plants arose recently in this country, these foreigners secured the contracts. And not only the contracts; but the foreign consulting engineer was called in to advise the corporations what machinery to buy and where to buy it, and this even to the extent of ordering steam-engines from the backwoods of America to be shipped to one of our largest engineering cities. The largest railway and other schemes in this country are not to be taken as the only possible systems, nor as the best systems. All that can be said about them is that they are the best the engineers engaged upon them can give. All things considered, other engineers might adopt with success quite a different system. Recently the question arose as to what was the best system for the London underground railways. Two systems were put forward. One proposed to use polyphase current throughout, with polyphase motors on the locomotives; the other, a system of polyphase generating and transmitting, with rotary transformers and stationary transformers and continuous-current motors on the locomotives and trolley. The question was decided in favour of the latter scheme, chiefly because the former one was new and untried on such a large scheme!

In consequence of all this control by foreign engineers the alternating schemes advocated by them have received undue attention, and have been accepted as the very best electrical engineering without much inquiry or criticism.

The superiority of the continuous-current electric motor is strikingly proven by the fact that it is found necessary to use rotary transformers in the large polyphase systems in order to secure the benefits of continuous current for the user. The polyphase motor has no great advantages to recommend it, while it has the drawback that its speed is not easily variable and its controlling gear is expensive; the absence of a commutator is of no importance at this date, for the commutator is now of no more trouble than the bearings of a motor. Polyphase current and motors can be used with advantage where the generator and motors are at long distances apart, and the motors are required to run at a constant speed. Under these conditions the use of a transformer is of great convenience at the motor end, and a polyphase system best on the whole. Like everything else electrical, the polyphase motor has been enthusiastically advocated, in season and out of season, for all and every purpose; but, while it has its sphere of usefulness, it will never entirely supersede the continuous-current motor, and it must be remembered that polyphase working applies only to power work; for all other electrical purposes it is useless or has little to recommend it.

It is, however, necessary to enter into the construction of polyphase motors to some extent. The polyphase generators present no features of novelty of much interest apart from ordinary alternators, from which they differ only in winding of the armature.

The inductor form of alternators, about which so much has been said, and the origin of which is ascribed to every one but the real inventor, is the general favourite. The diagram (Figs. 142 and 143) represent it as shown in Patent, No. 14,342 of 1890; it has been made larger since then, but not much different.

We will deal first with motors; as these are most likely to come within ordinary engineers' practice, we must consider them more in detail than the alternators.

There have been square yards of mathematical and geometrical demonstrations of the theory of induction motors, the whole essence

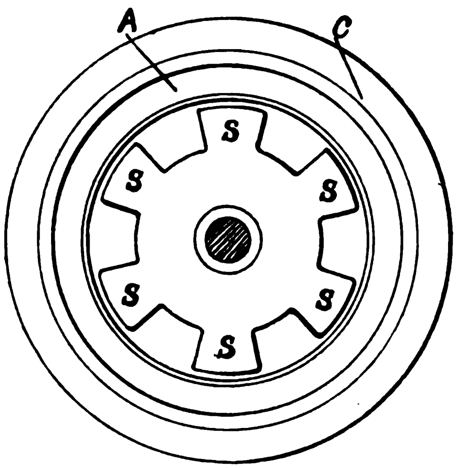


FIG. 142.—Induction Alternator, End View

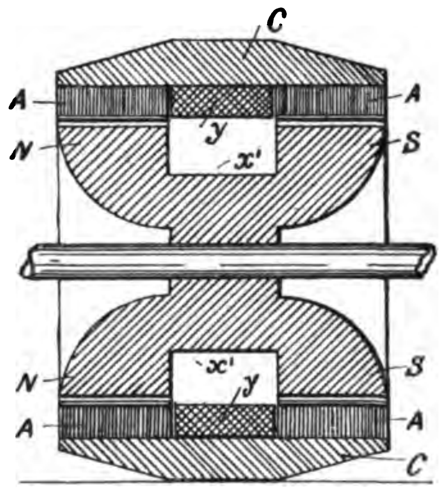


FIG. 143.—Inductor Alternator Section

of which amounts to nothing practical. The clock diagram and symbolic formulæ are only evidences of the want of some practical formulæ for designers' use. The case was the same with continuous-current generators and motors in early times. We had volumes of mathematical treatment, and wonderful and fearful expressions and theories by Clausius, Frolich, and others; but all of them combined could not answer the simple questions—What should be the cross section of a magnet? or what number of turns of wire to wind upon it to get a given result? We are pretty much in this stage with alternating motors. The mathematicians have laid hold of the rotating polarity idea, and, as it lends itself readily to clock diagram and symbolic exercises, it is worked for all it is worth and a great deal more.

As previously pointed out in Vol. II. this rotating polarity theory

is founded upon a fallacy, that is, upon the rotation of a copper disc over a rotating magnet. The rotation of a copper disc over an alternating fixed magnet is a totally different thing, as may be seen from pages 125–127, Vol. I. The less the rotary polar theory is studied the better.

The induction motor is a transformer, with one of its elements, generally the secondary, movable round an axis; and as a transformer it can be calculated out in all its parts. The only works on this subject are Eborall's "Society of Arts Lectures," and Professor S. P. Thomson's "Polyphase Machinery." Eborall treats the motor as a transformer; and in a very practical manner Professor Thomson in his book, "Polyphase Machinery," chap. xi., takes as a starting-point for designs of motors the surface of the armature required to radiate heat sufficient for cool working.

In my system we begin with the known quantities given us by the requirements of the motor. Every designer has the following data given to start with in regard to every motor he is called upon to design :—

1st,	Speed in revolutions per minute	=	N
2nd,	Peripheral speed . . .	=	n
3rd,	Voltage of supply . . .	=	E
4th,	Frequency	=	~
5th,	Horse-power required . .	=	H.P.

In addition to these he has a certain amount of common knowledge as to the disposition of conductors, insulation, and magnet winding, impedance, heating of conductors, and dissipation of heat.

First, then, as to speed. With alternating motors we are not at liberty to order any speed we choose as we can do with continuous motors; the speed depends on the frequency, and with a bipolar magnet the speed is the same as the frequency. With a frequency of 50 per second the speed would be 50 revs. per second, or 3000 per minute. In practice the speed is reduced to some multiple of the frequency, and the revolutions per minute are fixed by the formulæ P being

$$\frac{60 \times \sim}{P},$$

the pairs of poles per phase; so that with two pairs of poles we get

$$N = \frac{60 \times 50}{2} = 1500,$$

and with three pairs

$$N = \frac{60 \times 50}{3} = 1000.$$

Then as to peripheral speed I choose 3300 as a safe working speed, and this number becomes horse-power at once by multiplying by 10 pounds torque or pull.

E = A common voltage 200.

Frequency ~ should never exceed 50, and would be better about

30, but we have to deal with all frequencies on municipal circuits in this country. These having been designed by engineers who knew little or nothing about alternating machinery, so that we have 50, 60, 83, 100, and 130 frequencies in use, thus adding greatly to the difficulties in the way of alternating motors.

For example, we may discuss the dimensions of a 5 horse-power motor on a single-phase circuit at 200 volts, and a frequency of 50; the speed may be, as we have seen above, either 1000, 1500, or 3000, according to the number of pairs of poles. We will choose 1500, and therefore four poles must be used, two-pair.

The speed will be slightly less than this, owing to slip, but we are not going into all these differences; what is intended here is to show the *method* of designing, not to *design* a motor, although we will end with a motor design complete, only requiring here and there corrections for practical purposes.

The first step is naturally to find the torque required to give the horse-power, and thus torque $T = \frac{33,000 \times 5}{3300} = 50$. 33,000 the foot-lbs. per minute in a horse-power, 5 the horse-power required, 3300 the peripheral speed—we want a torque of 50 lbs. on the armature conductors.

Now the pull on a conductor in a magnetic field is in pounds

$$= 531\ c.l.\ B.\ 10^{-6}$$

where *l.* is the length in inches of wire in the field, *c.* the current in amperes, and B. the induction.

To simplify the calculations we can once for all settle upon an induction value for the air space between rotor and stator and decide upon a standard rotor conductor. A convenient standard would be a conductor one foot long and carrying 100 amperes, and might be called the Hectampere foot, or 100 ampere foot, such that the pull per foot of conductor carrying 100 amperes is constant for all motors, an induction of 6000 C.G.S. gives a pull of 4 lbs. approximately per 100 ampere foot, an induction corresponding to 6.5 in our English lines; hence we require $\frac{50 \times 100}{4} = 1.250$ ampere feet or 12.5 feet of armature conductor carrying 100 amperes = 1250 ampere feet.

We have now to consider the diameter and length of the rotor. The text-books say that considerable latitude is allowed in choosing these dimensions, but as a matter of fact there is no choice; when we have the speeds given, the diameter is fixed. It is that diameter which will give the peripheral speed = 3300; hence $\frac{3300 \text{ peripheral}}{1500 \text{ revolutions}} = 2.5$ feet = circumference = 29 inches, and the diameter corresponding to 29 inches = $9\frac{3}{8}$ inches; then the centre line of the conductors is to have a $9\frac{3}{8}$-inch diameter, outside diameter $9\frac{3}{4}$ inches.

We will take a squirrel-cage armature for example. We have

some freedom in the choice of the number of holes or slots for the conductors. A $\frac{3}{8}$-inch hole and $\frac{3}{8}$-inch space between would give 38 holes. It is better not to go deep into the core with larger bars.

Now, to find the length of the rotor we must calculate the total flux and the rotor current. A No. 3 S.W.G. copper rod will, with insulation, fit into the rotor holes, and this will carry 100 amperes easily ; and as we have found that we require 1250 ampere feet of conductor, so that $\frac{1250}{100} = 12.5$ feet of conductor is required in thirty-eight holes, the conductor must therefore be cut up into thirty-eight pieces. These would be $\frac{12.5 \text{ feet}}{38} = 3.3$ inches nearly, and allowing for insulation and space between stampings may be 4 inches long, the conductors under the poles therefore are to be each 4 inches long, but they must project at least an inch at each end of the armature, the bars would therefore be 6 inches in total length at least. As the rotor is 4 inches broad and 29 inches in circumference, $4'' \times 29''$ = area of air space between rotor and stator = 116 square inches, and this at an induction of 6.5 = 754 English lines as total flux ; the flux from one pole being one-fourth of this, or 188 or 1,100,000 C.G.S.

We now find the stator winding by the transformer formulæ

$$\text{Number of turns} = Nt = \frac{E\ 10^8}{4.45\ Z\ \sim}.$$

Hence frequency being 50 and volts 200

$$Nt = \frac{200 \times 10^8}{4.45\ Z\ 50}.$$

Z is found by taking the area of one polar face = to a fourth of 116 in this case, and multiplying by the flux per square inch, or B. There are 29 square inches on this surface. An induction of 6000 C.G.S. is equal to 38,700 per square inch, and

Total flux = 38,700 × 29 = 1,100,000 from one pole C.G.S. approximately. Hence we get

$$Nt = \frac{20{,}000{,}000{,}000}{4.45 \times 1{,}100{,}000 \times 50} = 83$$

= 83 turns per pole, and as each turn goes through two holes on the stator, and there are four poles, we get $2 \times 83 \times 4 = 664$ wires counted all round the stator slots. There are forty stator slots. Hence

$$\frac{664}{40} = 16 \text{ wires per slot.}$$

This number could be laid in two a side and eight deep.

We have now to find the current in each wire of the stator. We may allow 900 watts per horse-power, and by dividing watts by volts, we get $\frac{5 \times 900}{200} = 22.5$ amperes, a No. 12 S.W.G. wire will carry this current. Finally, we find the depth of the stator above the slots at *a. b.* This carries half the flux of one pole = 550,000 at a density of 55,000 per square inch. Hence we get $\frac{550{,}000}{55{,}000} = 10$ square

inches, and as it is 4 inches broad, we get $\frac{10}{4} = 2.5$ inches as this dimension. The slots are 1.25 inches deep. Hence the total depth is 3.75 inches, and $2 \times 3.75 + 9\frac{3}{4} = 17\frac{1}{4}$, the diameter of the stator stampings outside.

We have now obtained the following data for our design :—

Horse-power, 5.

Watts input, 4500.

Stator stampings, inside $9\frac{3}{4}$ ins., outside $17\frac{1}{4}$ ins.; 40 slots; 16 wires, No. 12 S.W.G.; slots $1\frac{1}{4} \times \frac{3}{8}$ ins.

Rotor squirrel cage, 38 holes, $\frac{1}{4}$-in. wires each 6 ins. long; iron stampings, $9\frac{3}{4}$ diameter outside; holes $\frac{3}{8}$ ins. diameter.

Speed, 1500; torque, 50 pounds; peripheral speed, 3300.

Compare this simple process with that given in some text-books, and it will be found much clearer to most students. Motors are made to produce torque, not heat; hence, that is the chief factor and the natural starting-point. From that we proceed to ascertain the ampere feet required at a moderate induction value to give this torque. The diameter of the rotor is found at once from the two speeds, one of which is fixed by the frequency. Having got the diameter, the number and size of holes is easily settled. We then get the current which the wire will carry comfortably, and with this we divide the ampere feet to get the length of conductors in the rotor; and this total length, divided by number of holes, at once gives the length of the rotor. We next deal with the stator as the primary, and, as shown, find the winding and dimensions.

In addition, in single-phase machines starting coils, as will be explained later, must be provided on the stator.

Fig. 144 shows this machine to $\frac{1}{4}$-scale. The clearance between the rotor and stator must be exceedingly small, $\frac{1}{64}$ of an inch; and as there is a strong pull on the rotor, the shaft must be very rigid, and in long, perfect-fitting bearings. The efficiency depends onthis close fit.

It is interesting to note that we can design continuous-current machines starting from the same point the torque. For example, take a 5 horse-power motor, same given requirements :—

200 volts,
1500 speed,
3300 peripheral speed.

Here, again, the torque will be 50 lbs., 6000 would be a good induction in this case also. The working current and pressure come directly on the armature or rotor winding in a continuous-current motor, not upon the stator as in the alternator. And there is no counter E.M.F. in the continuous-current field-magnet coils, but we can proceed with these facts in view and calculate an armature.

Kennedy's Induction Motor

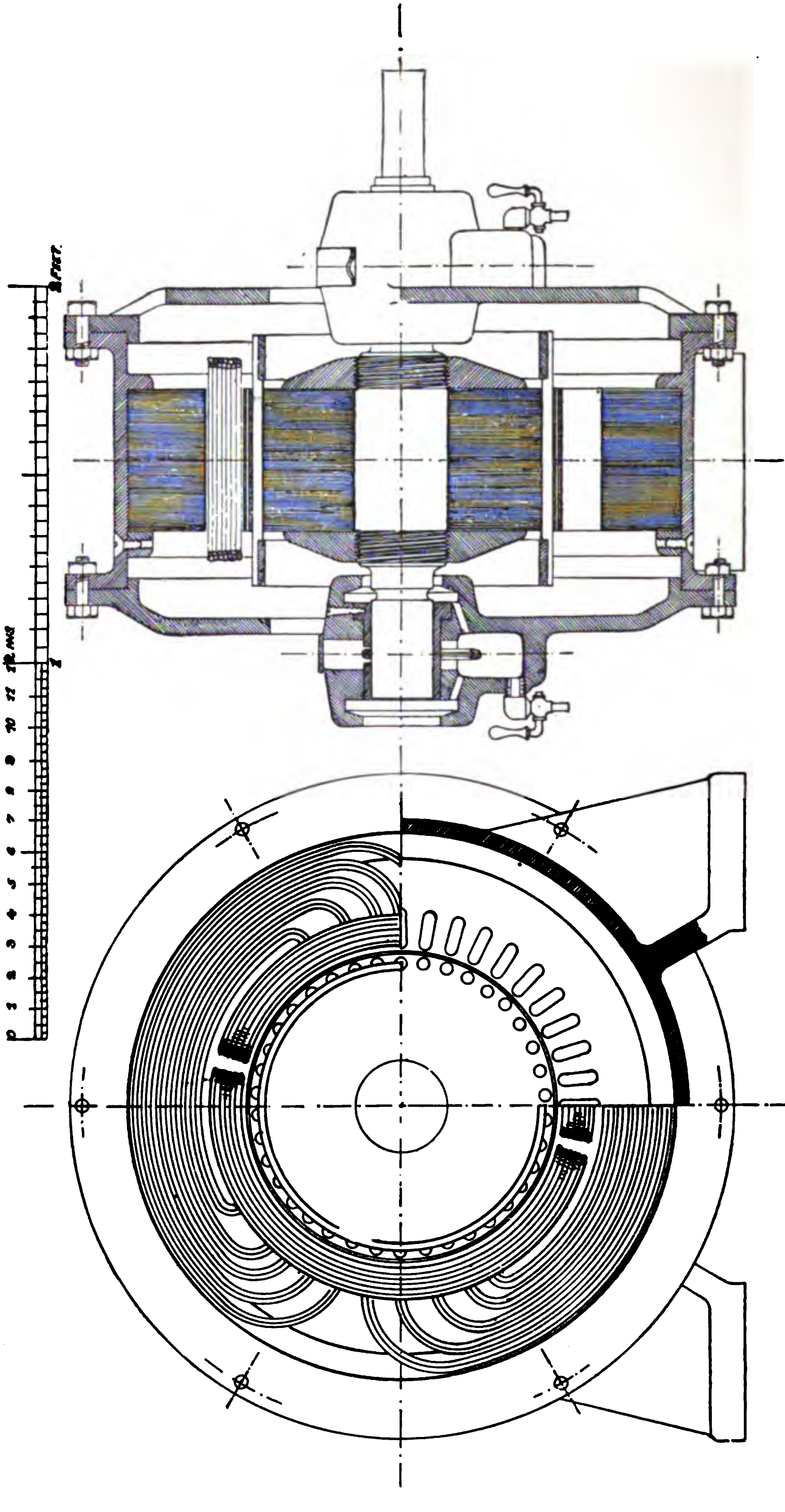


FIG. 144.—Dimensions of Single or Two-Phase Motor calculated from Hectampere foot and Torque Formula

Torque Calculations Continuous Current

The armature would still be $9\frac{3}{4}$ inches diameter, for the peripheral speed fixes that, and it would be also four-polar; but the gaps for commutation are cut out of the polar surface, so that we would have by taking the whole circumference = 29 and cutting out four $2\frac{1}{2}$ gaps = 10 inches in all, then 29 − 10 = 19 inches total arc of 4 poles, and we then find the breadth or length of armature as we did before for alternating. We will keep to same number of armature slots, 38; the total current in the armature will be same as in stator of alternator, 22.5 amperes; but in a four polar the conductor under each pole, if parallel wound, would carry only one-fourth of this = 5.62 amperes. The total torque is 50 lbs.; torque of one pole will be $\frac{50}{4} = 12.5$ lbs, and, as 100 ampere feet gives 4 lbs. torque, we have

$$\frac{12.5 \times 100}{4} = 312$$

ampere-feet required under each pole. This divided by the amperes will give the feet under one pole, $\frac{312}{5.6} = 60$ feet nearly of wire, or 720 inches. Now in the armature there are 38 slots, but only about $\frac{3}{4}$ of them under the poles; about 7 slots under each pole face, so that we get in each slot under a pole $\frac{720}{7} = 103$ inches of wire in each slot. Now the slots are $\frac{3}{8} \times 1\frac{1}{4}$ inches, and must carry wires of sufficient section to carry 5.62 amperes; a No. 16 S.W.G. wire would be ample in section. Into these slots we get easily 30 wires of this size, 3 side by side and 10 deep, and $\frac{103}{30} = 3.4$, or say $3\frac{1}{2}$ inches length for armature core, to which something must be added for insulation.

Now so far we have arrived at our continuous-current armature at 6.5 induction per square inch in air-gap, and armature conductors = 1140 total counted all round. This would, with the current given, produce torque for 5 horse-power at 1500 revs.

The continuous-current stator or field has not, like the alternating stator, to receive all the energy of the motor, but only sufficient to maintain the field flux—requiring only about 3 per cent. of the power of the motor. If the student follows the calculation he will find total flux = $19 \times 3.5 \times 6.5 = 430$ total flux and $\frac{430}{4} = 107$ flux from one pole, and the counter E.M.F. = $Z \times n \times Nt\ 10^{-6} = 107 \times 1500 \times 1140 = 182$ volts.

In this system of treating the problems in designing induction motors, we are not called upon to assume any important dimensions, but follow up the design from the natural existing and given data; and I have gone into it at some length as this is a new method, and one which brings the principles of the designing of dynamo electric machinery out into much better definition than the method of assuming certain factors and commencing with a heat-radiating surface.

Induction Motor Stampings

A reference to Fig. 144 shows the general construction of the motor as calculated out with the special stiff shaft and rigid

FIG. 145.—Stator and Rotor Stampings

bearings, and Fig. 145 represents the form of stamping generally employed in building the rotor and stator.

Fig. 146 illustrates the actual stampings for the alternating

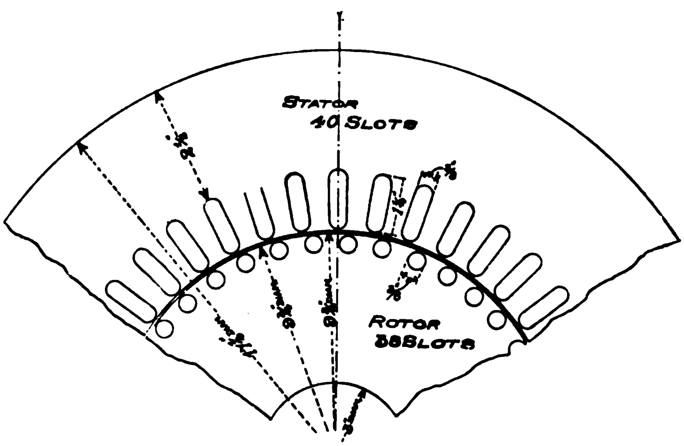


FIG. 146.—Stampings as calculated for Motor on page 154

induction motor as calculated out—40 slots in the stator, and 38 in the rotor.

Such single-phase motors are not self-starting, and many devices

are resorted to in order to make them self-starting. When the armature is at rest we have already seen, in the fundamental induction motor, a disc of copper over an alternating magnet, Fig. 159, page 125, Vol. I., of this book, the currents in the rotor circulate symmetrically round the poles formed on the stator, hence there is no more tendency to rotate one way than the other. But if the rotor is spun round in either direction when the stator current is turned on, it will start going itself when the speed has been brought up above a certain value. And some small motors are started much as a spinning-top is, by a string wound round the shaft and quickly pulled off. A simple induction motor will run in either direction it may be started in. As a rule the speed must be by

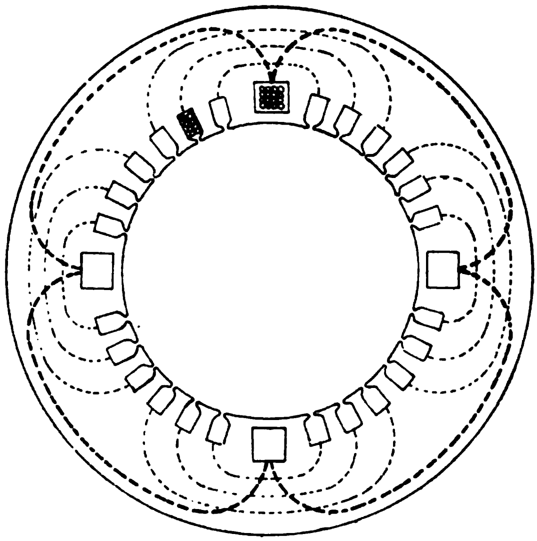


FIG. 147.—Stator with Starting Coils

artificial means brought up to half synchronism before they will run alone. It will thus be seen that single-phase induction motors will not start with a load on, for in that case it is very difficult by any known artificial means to get the initial speed up to over half synchronism; indeed it is difficult enough on no load. It is therefore necessary to start on a loose pulley, or some clutch device whereby the load can be slid on after full speed has been attained. The Fuller Wenstrom motors have a very neat friction-clutch pulley which works like a governor by centrifugal force, so that, when full speed is attained, the pulley is gripped on to the shaft automatically.

Any motor above a toy cannot of course be started by spinning the rotor by a string. The usual device is to wind the stator with two windings as if it were a polyphase stator, one a working winding, the other a starting winding, and then by some means to shift the

phase of the currents in one of the windings, by means of a choker or condenser, or both, so that it acts as a polyphaser to start with. Fig. 147 shows a diagram of a four-polar stator with two windings; the small holes contain the working winding, the four large holes the starting winding. At starting the rotor also plays an important part in the difficulty if short circuited or squirrel-cage type, for the large currents generated in it when at rest demagnetise the stator, lowering its counter E.M.F., and thus allowing large stator currents to flow. Hence again in all but very small motors some means for introducing resistance into the rotor-conductor circuits are necessary. And, as in a continuous-current rotor, the counter E.M.F., in its conductors, increases as the speed rises; this rotor resistance is cut out gradually as the speed increases, until at full speed it is all out. Of course a plain squirrel-cage rotor cannot be used with a resistance without considerable modification, so that we must adopt a wound rotor on all larger motors.

In our example of calculations for a single-phase motor we did not allow for these necessary additions. The starting winding will require some slots on the stator, and, as shown in Fig. 147, may occupy one-fourth of the inner periphery; the design must therefore be modified with this in view. The best way to do this is to make the working slots wider and deeper so as to accommodate the winding as before found, and to thus leave room for the starting winding. The starting winding may be worked at a very high current density, as it is only in use for a very short period, perhaps up to a density of 4500 per square inch with safety.

With a frequency over 60 per second rotors are not satisfactory with simple squirrel-cage winding, so that for motors over 3 horse-power for single-phase and 7 horse-power polyphase a winding is necessary.

In single-phase motors the difference in phase produced by any device in the two windings at starting is small and irregular, and the reaction of the rotor very great. Hence even at the best the starting torque is small; but with a wound rotor and resistances this rotor reaction is reduced, so that a good starting torque is produced with no abnormal stator current.

Mr. C. E. L. Brown's starting devices for single-phase motors may be taken as typical. For small motors Fig. 148 represents a simple arrangement in diagram; R is a non-inductive resistance, W the working resistance, and Y the starting resistance, S the starting switch. The resistance R is put in parallel with the starting circuit at the start as shown, and causes a difference of phase between W and Y as soon as the speed is nearly that of synchronism, the switch S is thrown over so that the winding W alone is on the mains.

Fig. 149 is the same arrangement, only a condenser C is used

in place of a non-inductive resistance. An electrolytic condenser is often used for this purpose, that is, a series of secondary cells with

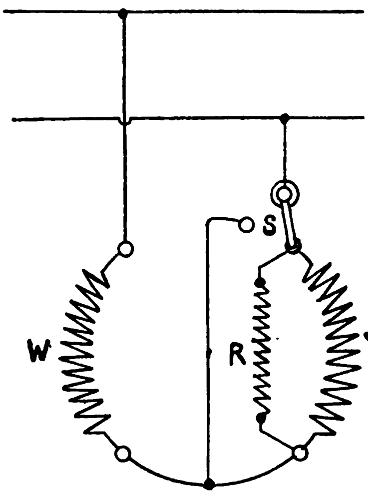


FIG. 148.—Starting Devices

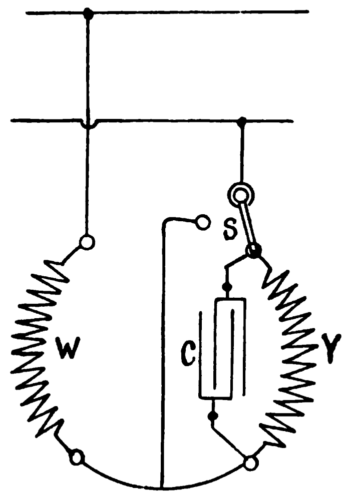


FIG. 149.—Starting Devices

iron plates in a solution of soda, an arrangement to be described presently.

In both the foregoing devices the resistance or condensers are in

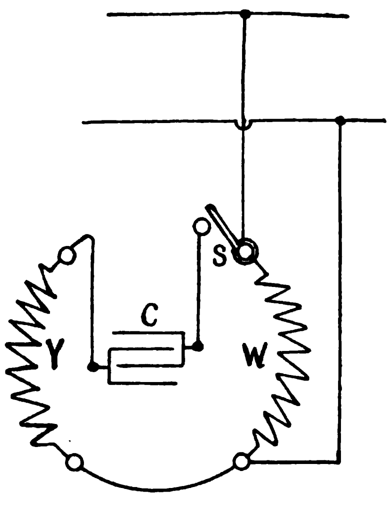


FIG. 150.—Starting Devices

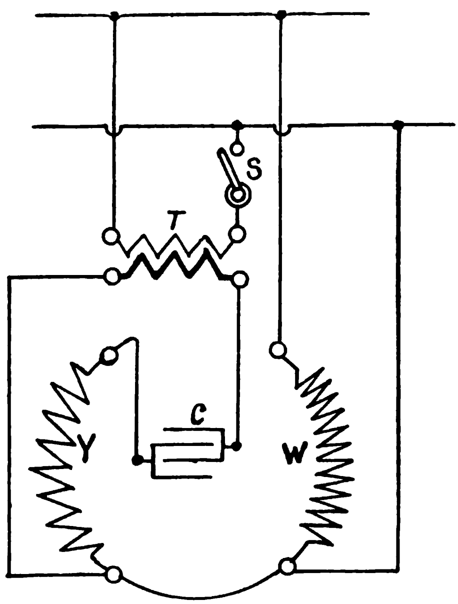


FIG. 151.—Starting Devices

parallel with the starting coil, but we can also put them in series, so that the connections are as shown in Fig. 150.

Induction Motor Starting Switches

When extra high-pressure motors are employed, a transformer is put in the circuit of the starting apparatus, as shown in Fig. 151, and,

FIG. 152.—Starting Switches

when full speed is obtained, the primary is switched off by switch S.

The diagrammatic figure pretty well illustrates a starting switchboard for a wound rotor single-phase motor. A double-pole switch for

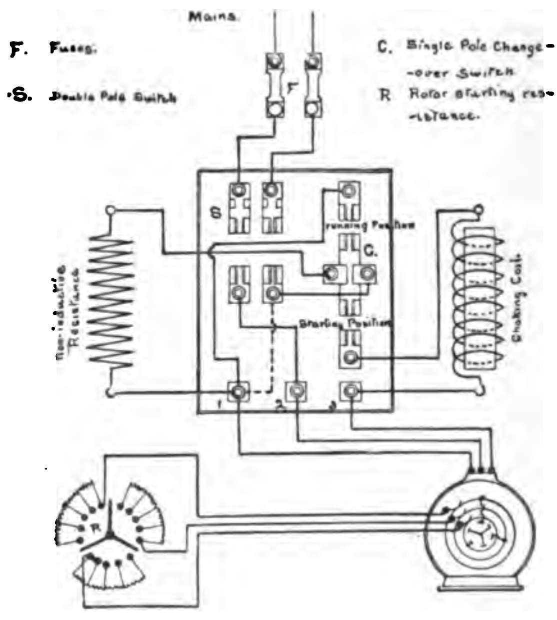
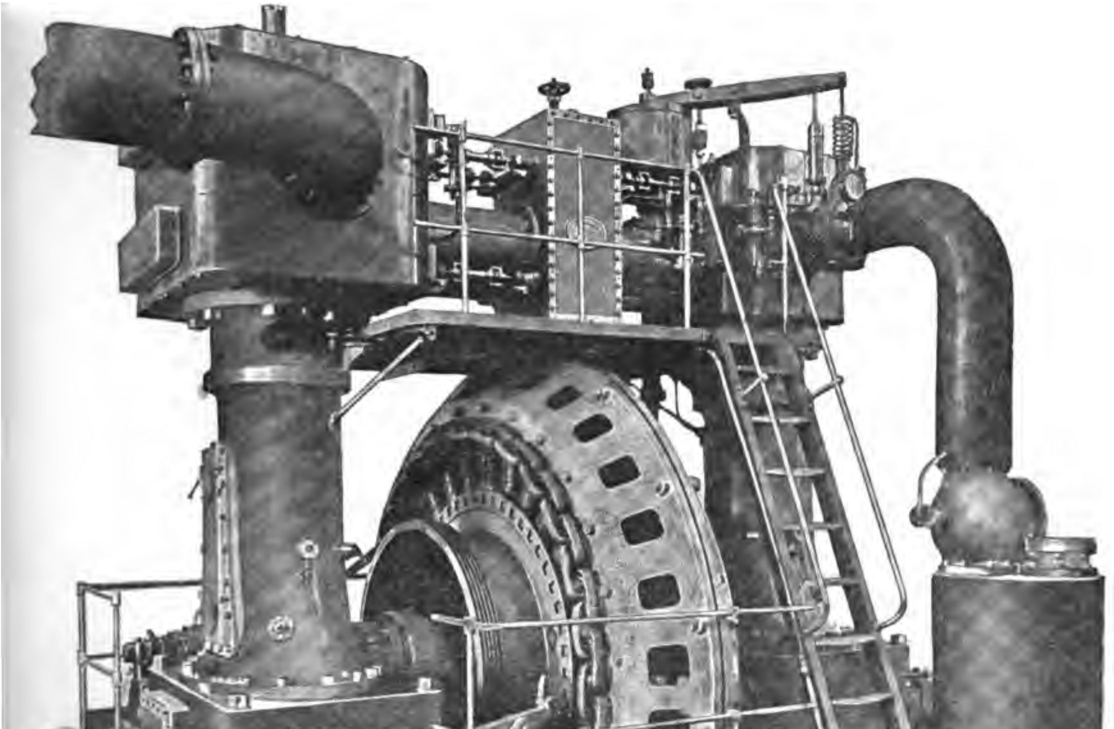


Diagram of Starting Apparatus for Single Phase Motors.

FIG. 153

two ways and a single-pole two ways, such as are shown in Fig. 152, are required, also a non-inductive and an inductive resistance. The



Two-Phase Generator Ferranti Set,
Showing the Two Sets of Coils on the Stationary Armature

non-inductive is put in parallel or series with the starting current, and the inductive resistance with the working circuit of the stator ; in the working position these are cut out by throwing over the switches. The rotor resistances are shown at R, there being three slip rings connecting three circuits on the rotor ; as speed rises these resistances are cut out, and, when full speed is obtained, the double-pole and single-pole knife switches are thrown over into working position, Fig. 153.

Another method of working the resistance R in the rotor circuits is to attach the resistances of the best average value to the brushes, and, by means of a sliding conducting spring ring operated by a handle, short circuit the resistances by pressing in the spring

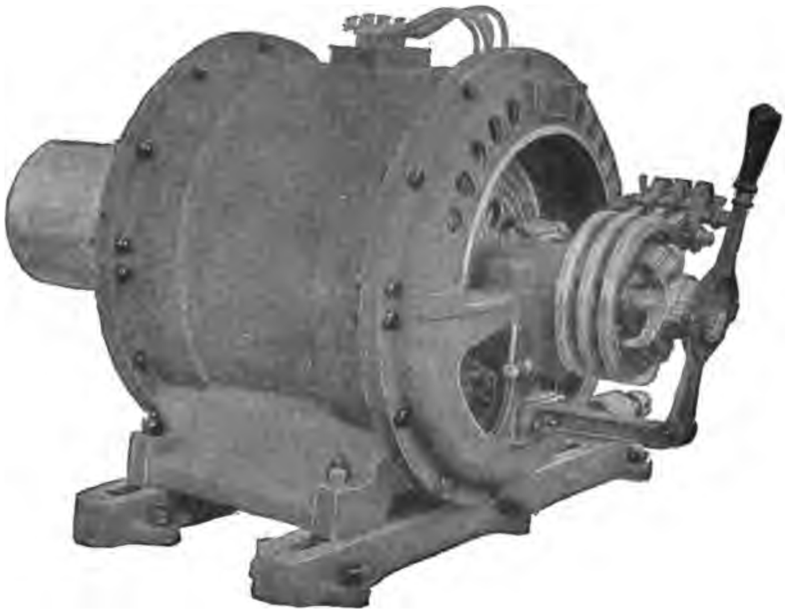


FIG. 154.—Motor Starting Devices

ring when full speed is attained. This device is shown on the motor of the General Electric Company, Fig. 154.

A more perfect and easier worked switch is made by the same firm for controlling alternating motors, in which the whole apparatus is in a case, controlled by one rotating handle.

The Thomson Houston Company have a device for working three-phase motors on single-phase circuits. Two of the stator terminals are connected to the mains through a switch, as shown in Fig. 155, and the third terminal through a compensating transformer shunted by a condenser; by this means the single current is split into three, all differing in phase. It is, however, necessary to keep the transformer and condenser always in circuit, so that they need to be ample in dimensions.

In Fig. 147, already referred to, the arrangement is one made by Heyland, whose motor is referred to in Vol. I. In this device no condenser or resistance is required; the starting coils are closed circuits at the start, and they act as secondary circuits in which a large current is induced, differing in phase and producing a considerable torque. When the speed is up to nearly full, the circuit of these coils is broken.

The polyphase motor does not differ much from the single-phase; only it requires no starting coils on the stator, and the stator winding is divided into sections distinct for each current separately, and the rotor windings are arranged as for a two- or three-phase generator.

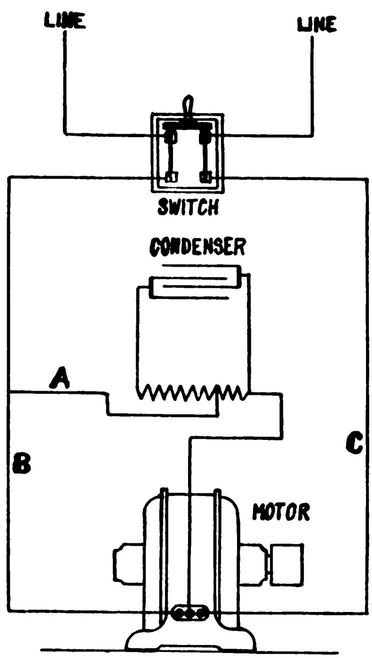


FIG. 155.

The diagram (Fig. 156) shows a curve of the efficiency and power of a Fuller Wenstrom single-phase motor.

A single-phase synchronous motor of simple design is a useful apparatus for many purposes, especially for rectifiers to convert from single-phase to a pulsating unidirectional current. Fig. 157 is a diagram of such a small machine. The rotor is of steel magnets permanently magnetised and mounted between two discs truly on an upright shaft; there are six, eight, ten, or twelve magnets, according to the frequency and speed. The stator is fixed, and is made of laminated stampings, like those shown for the single-phase motor, Fig. 146, page 156, and wound with six coils, all in series, but one-half of them wound in the opposite direction to the other half, forming alternate NS NS NS poles all round; when excited by a continuous current the coils may be wound gramme ring fashion. A stator of 40 holes on an 8-inch bore, with holes 1 inch by $\frac{5}{16}$ inch wide, will suffice, and about $1\frac{1}{2}$ inch broad and $\frac{3}{4}$ inch above slots wound full up with No. 20 cotton-covered wire. Fig. 158 is a plan diagram.

The commutator consists of a split tube, having three positive and three negative sections. The line current enters the whole part of the tube, and is rectified on the split part. The ends of the stator winding go straight through a variable resistance to regulate the current from the mains.

The brushes are carried on a rocker in order to allow of adjustment to avoid sparking. Sparking cannot be avoided entirely, for

there will be always a blue static spark at the toe of the rectifying brushes, but that is of no importance and harmless; it is the red-tinged

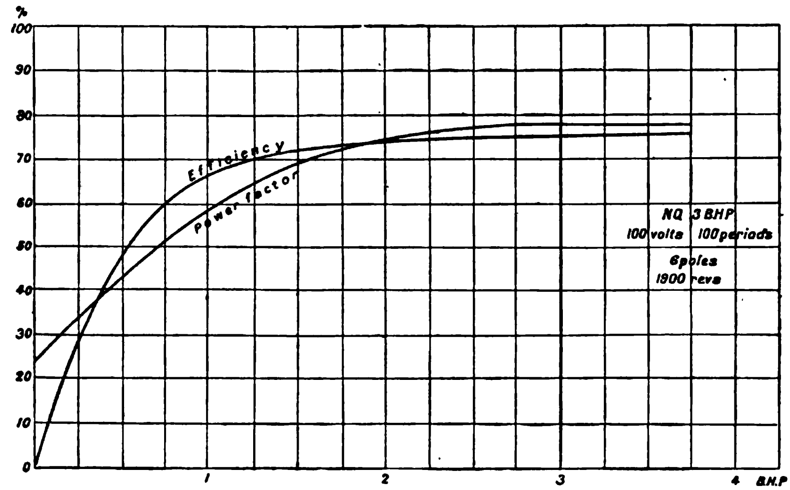


FIG. 156.—Efficiency Curve

angry-looking spark, due to short circuit, that is dangerous and to be avoided by careful adjustment of brushes in a rectifier. We have already described the Ferranti rectifier in Vol. II.

The motor referred to in Vol. I., page 128, can be constructed

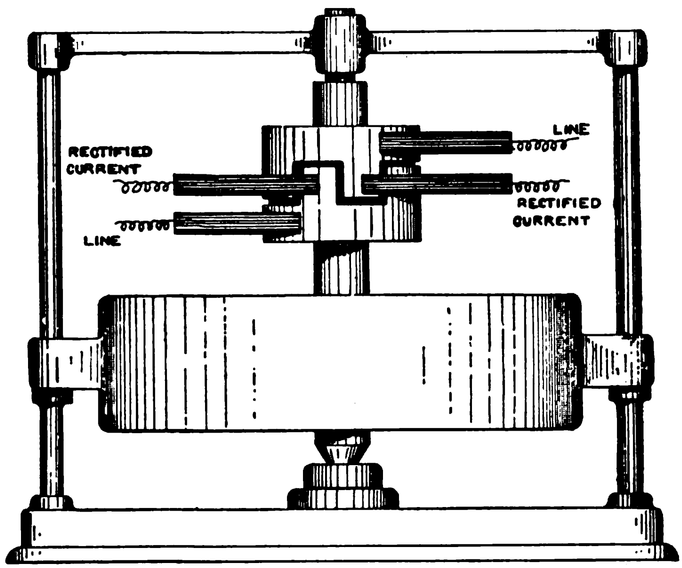


FIG. 157.—Small Rectifier

as a single-phase machine, and is easily started by exciting one stator with a resistance in circuit, and exciting the other with an

inductive resistance in circuit, so as to produce a difference in phase between the two circuits. As speed increases, the resistances are cut out, and the current thrown on direct.

This design has the advantage that there is no waste of space on the stator, due to making room for starting coils. The poles of the two stators are staggered, and the rotor winding or bars run straight through. It starts as a two-phase motor, and afterwards runs as single-phase.

Little fan motors may be made with steel rotors, solid and with a four-pole stator, and may be started readily by whirling the fan round by hand, and thus save the expense of the starting devices in these small machines.

The squirrel-cage rotor is next in order of evolution, and may also, in small sizes, be started by hand on no load. But in most cases the stator windings are either wire wound or bar wound, in a precisely similar manner to those of the corresponding generators; but, as it is of the greatest importance to have a small winding depth and an even division of poles, such windings are generally carried out in four or more holes or slots per pole per phase; for three-phase working the coils are connected up in either star or mesh fashion, but generally the former method is used for all sizes of motor. The stator coils of *three-phase* motors are always arranged (except in some small two-pole motors for no more than 25 cycles) in such a way that, considering one phase, for instance, all the coils of this phase are wound in the same direction, and produce magnetic poles of the same sign, poles of opposite sign being thus produced between them. The stator winding per phase is thus in principle the same as the field magnet winding with a coil on each alternate pole, and there are thus two coils per phase for a four-pole motor, three for a six-pole motor, &c.; the principal object of this is to economise space on the internal periphery of the stator, and it attains this without presenting any serious disadvantages.

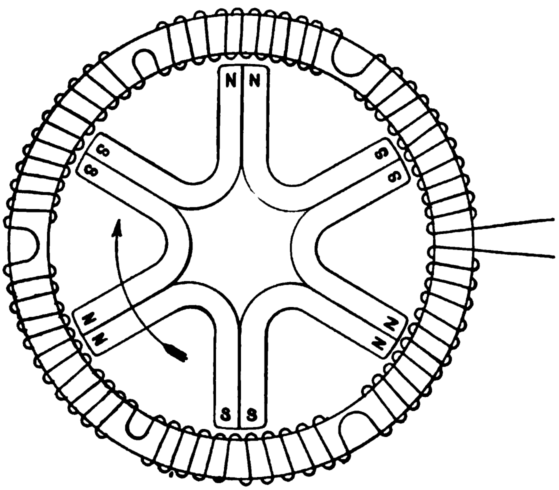


FIG. 158.—Rectifier

The cheeks of the stator cores are best made of gun metal, as the eddy currents which would be produced in them by the leakage

along the side of the stator practically prevents such leakage altogether. An important feature connected with the design of the stator core is its arrangement in the cast-iron containing case. In well-designed motors the core is always supported away from the case, that is to say, it is supported by radial ribs cast on the inside of the case. An effective circulation of air is obtained round the stator core, which is of great assistance in reducing the heating of the core, due to the stator losses.

As to the actual clearances between stator and rotor, the following table given by Eborall is interesting on this very important point in induction motors :—

Rotor Diameter.	Air-gap Length.
Up to 4 inches inclusive . . .	0.010 inch.
Between 5 and 8 inches inclusive .	0.015 „
„ 9 „ 12 „ „ . .	0.020 „
„ 15 „ 20 „ „ . .	0.035 „
„ 24 „ 32 „ „ . .	0.080 „
„ 40 „ 60 „ „ . .	0.125 „

The above dimensions do not apply to induction motors used for traction purposes, which always have larger clearances than those given above; this is necessary on account of the considerable shocks to which such motors are unavoidably subjected, which have the effect of causing considerable wear on the sleeves of the bearings. In traction work, it would be nearly impossible to keep these sleeves in such a condition that the clearances given above would be safe, partly on account of the cost of the constant renewals, and partly on account of the incessant amount of inspection that would be necessary. As a rule, therefore, the clearances of such motors are about 50 per cent. greater than with standard stationary motors.

To vary the speed of induction motors, resistances are inserted in the rotor circuit, exactly as we do in the case of continuous-current motors. It is a wasteful method in both cases. For this reason, and also in order to insert resistances in the rotor at starting, in all but very small machines a winding is employed on the rotor general in three sections, terminating in three slip rings to making contact by brushes, the connection being usually star, bar winding being most common. A few hints from Mr. Eborall on general points are instructive :—

" Wound rotors may have either coil or bar windings, the latter being, as a rule, preferable; in either case, as soon as the rotor has run up to normal speed, the starting resistance is short-circuited, and, in the most modern constructions, the brushes lifted off the rings, and the latter simultaneously short-circuited by means of a clutch. In this way all wear on the rings of the motor during running is prevented, together with the C^2R and friction loss which

would otherwise take place on account of the rubbing contacts; the former loss with large motors would not be negligible on account of the large rotor currents and the unavoidable brush contact resistance, and it is therefore well to do away with it in the manner indicated.

"At starting, the pressure between any two slip rings is determined by the impressed terminal pressure and by the relative number of turns on the stator and rotor, as in a transformer; this pressure decreases to zero as the motor runs up to speed, and the rings are short-circuited. Particularly for high-pressure motors, therefore, it is advisable to have a high "transformation ratio," that is to say, to use bar windings on the rotor, although these windings cost a little more than wire-wound coils would do. Moreover, on account of the heavier rotor current, the brush gear may cost a little more, and the starting resistance will cost more. The latter is frequently immersed in oil in order to reduce its size by getting rid of the heat developed during starting.

"Star-connected rotor bar windings have usually one or two bars per slot and are unsymmetrical, necessitating the use of 'false connections.' The common junction of the winding is frequently made on the rotor spider.

"To sum up, we may say that the whole design of a successful induction motor must be such as to reduce magnetic leakage to a minimum, for, if this point is not attended to, an indifferent motor, having a low power-factor at all loads and a small starting torque (for a given current consumption) and small overload capacity, will result. To this end, the breadth of the cores will be kept small, the air-gap will be made as small as it can safely be made from the mechanical point of view, the winding depths will be kept down (that is, the depth of the slots will be small), drum windings will be used, and the stator and rotor teeth will be worked at a fairly high flux-density. Further, the pole-pitch will be made as great as possible, or, in other words, the number of stator poles for a given diameter will be as small as possible, in order to increase the length of the leakage paths from pole to pole; this implies either a low frequency or a high speed, and thus motors operating at definite frequencies, such as 40, 50, or 60 cycles, should always be run at as great a speed as is practicable."

Fig. 159 shows the switch and connections to the three slip rings of a three-phase motor, with the three resistances for starting under full load, and a three-pole switch.

Fig. 160 represents a diagram of alternating generator of the inductor type, which has some interesting features. It was first introduced by Kingdon and afterwards by Steinmetz. The field is an ordinary multipolar, and on the pole-faces coils are placed for

Ferranti Field Magnet for Copper Armature Alternator

armature coils, either on projecting teeth or in slots; the inductor is built up of stampings, with teeth twice the pitch of the teeth on the pole-faces. It therefore gives a two-phase current. It may, however, be made single-phase or three-phase.

Fig. 161 is worth noting, as it contains the foundation of a good

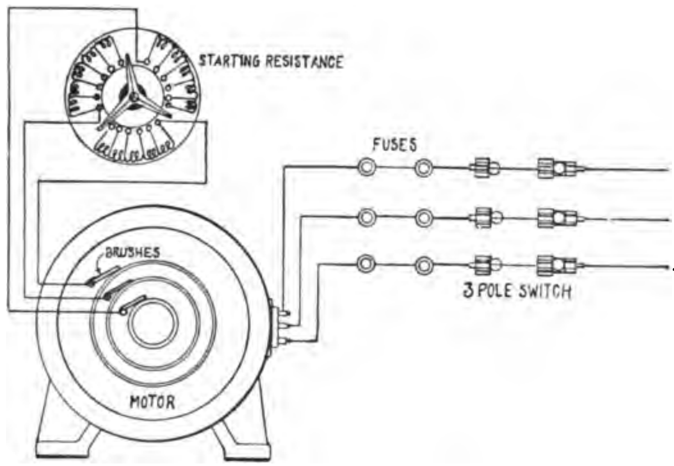


FIG. 159.

type of machine for steam-turbine ship-lighting plants, inasmuch as on these lines a generator could be built with no commutator and no sliding contacts. It is a self-exciting alternating-current generator. The multipolar rotating field magnet F is mounted on the same shaft with the armature *a* of a magneto-electric generator, and each is provided with the same number of coils, those on the field magnet

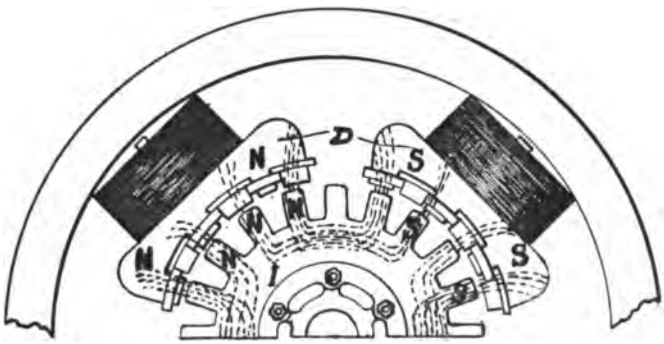


FIG. 160.

being connected to those on the armature by wires H, without the intervention of a commutator. The permanent magnets of the magneto machine are built up of laminated steel plates N connected by a yoke *y*, and bound together by bolts *g*, plates *h*, and wooden packing-pieces M. The field magnet F is built up of a number of

toothed laminæ. The armature A is fixed and is wound with coils A^1 after the manner of a Gramme ring. The figure and description are taken from specification of patent No. 18,491, 1890.

We may now pass on to the consideration of alternating generators, more particularly three-phase machines, as these are of much greater importance than single-phase machines and two-phase machines. The huge blunders of the past made in installing single-phase alternating machinery of high frequency are not likely to be repeated. If alternating systems are ever again to be considered suitable for generating for public supply, the generators should be three-phasers.

Alternators may be classed according to the design of the armature :—

1st. Copper alternators, so called because there is no iron in the

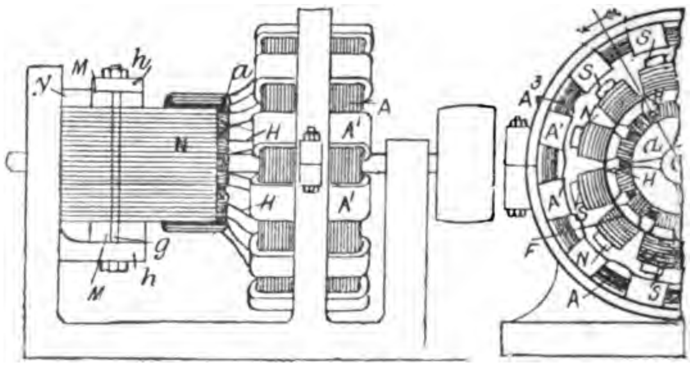


Fig. 161

armature. A good example of this is shown in the plate of Ferranti's copper armature.

2nd. Iron alternators, having an iron-cored armature.

The first type may be at once dismissed as far as polyphase working is concerned. As a single-phase machine for lighting it is useful, although difficult to design a good mechanical and electrical construction.

The iron-cored machines may again be divided into :—

Rotating Field Alternators.
Rotating Armature Alternators.
Inductor Alternators.

The copper armature has not enough impedance for large, heavy, slow-speed machines to run in parallel, and the flimsy construction allows of much vibration and noise. In modern working the copper is embedded in slots in a laminated iron core, generally fixed, and the field rotated. In Plates of Ferranti machines the construction of the Ferranti copper armature is very well illus-

trated; and in the figure of the Ferranti engine and dynamo we have already shown the two-phase machine between a pair of engines supplied to the Wakefield Corporation. This machine was of special design, so that it would be possible to obtain 400 K.W. from either of the two phases, though the output of the engine is only that sufficient for a normal load of 400 K.W. and an overload equal to 500 K.W. for two hours. It will therefore be seen that the alternator is really an 800 K.W. alternator; and it runs at 258 revs. per minute, giving a pressure of 2200 volts per phase, frequency being 60 per second.

The copper disc armature shown in Plate was supplied to the Derby Corporation. Each pair of coils is drawn in radially

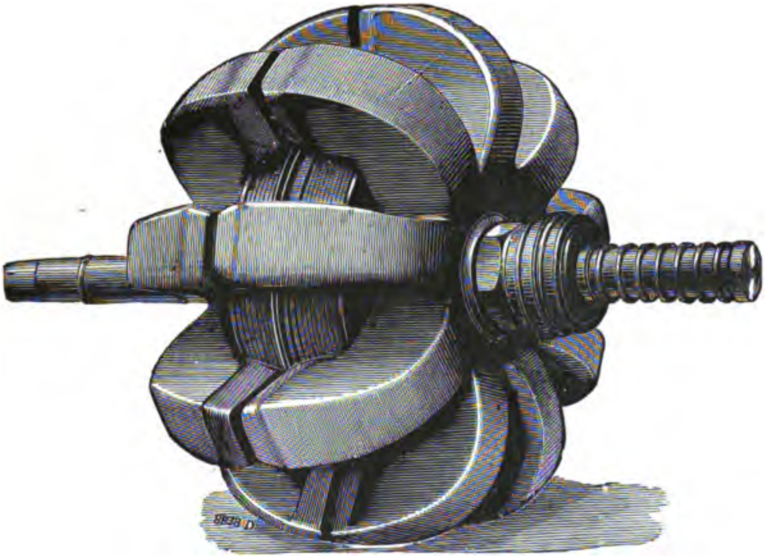


FIG. 162

by strong bolts. The field magnet is shown in the following Plate. The output of the machine is 600 K.W. at 214 revs., at a pressure of 2100 volts; frequency 50 per second.

Mr. Mordey's copper disc alternator has a rotating field and a fixed disc. The field is of cast steel.

It will be noticed from Fig. 162 that the hub and shaft form the core of several pairs of radiating magnetic poles, the field winding of which is common to all and wound concentrically with the shaft; hence all the magnet poles on one side of the polar gap will be of one sign (say north), and all those on the other side of the opposite sign (say south); consequently, as there is no magnetic leakage between poles of the same sign, all the magnetic lines must cross the small air-gap in which the armature coils are placed, with highly efficient results.

The armature, Fig. 163, consists of a ring of bobbins wound on non-metallic cores, and rigidly held to the gun-metal ring by special clamps.

Messrs. Siemens Bros. first introduced the copper disc armature alternator for arc lighting twenty-two years ago. Messrs. Crompton & Co. also make a copper disc alternator. They are, however, in many respects, especially mechanically, inferior to the iron-cored machine. A field magnet on somewhat similar lines as Mordey's has been used by C. E. L. Brown, only the pole faces are on the outer periphery, NS NS. But, finally, the common practice has come down to the use of multipolar fields of radial poles iron clad, or each pole with a separate exciting coil. A rotating field radial pole built of stampings with coils on each pole, and held there by retaining wedges of non-magnetic metal.

FIG. 163

The iron-clad induction type of magnet now so much in favour was invented by the author in 1899, and patented (No. 14,232) 1890. A brief reference has been made to it on page 149. Fig. 164 represents the first machine of this kind, made to the author's designs, for two phases, each 20 amps. and 2000 volts. It was further improved, as explained in the patent specification, by laminating the inner periphery of the fixed armature, and laying the coils in or upon that periphery; the construction being then like Fig. 165. It has a single stationary exciting coil, no revolving windings, and requires no sliding contacts. It has its disadvantages, and, in my experience, is inferior to the radial pole machine with separate windings for larger machines. It has a deleterious magnet leakage; armature leakage is great, and more injurious than in other types; the field is heavy, and requires strong construction.

The exciting coil forms a core surrounded by an iron shell, formed of the fixed armature core and the revolving field, giving all the polar projections upon one side a north polarity, and those on the other a south polarity. The important point to notice is

that the magnetic flux is never reversed. There are two distinct armatures, one armature being acted upon by a crown of N-poles, the other by a crown of S-poles. The two armature windings are connected either in series or in parallel with one another, but preferably the former, as with the two windings in parallel, internal currents may circulate in them, due to small differences, very difficult to avoid, in the respective waves of induced E.M.F.

In order that each armature may have a symmetrical alternating E.M.F., precautions have to be observed with regard to the arrangement of the armature winding relative to the inductor poles. When one side of an armature coil is being acted upon by a pole, the other side of this coil must lie in the space between two poles. For overlapping windings the ratio of pole breadth to pole pitch is about 0.8.

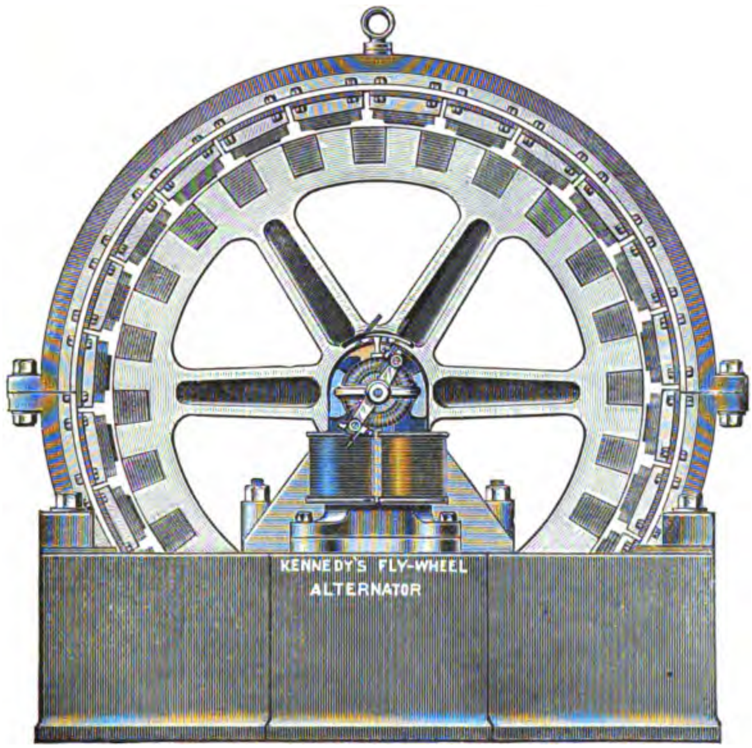


FIG. 164.—First Fly-Wheel Inductor Alternator, 1891

The pole pitch in radial pole alternators with alternate poles is equal to the distance from centre to centre of the pole faces on the periphery at the air-gap; but in inductor machines it is equal to half the distance between the centre of the pole faces at the air-gap, or equal to the distance from the centre of the pole to the centre of the space between the poles.

Characteristics of Inductor Alternators

In the little inductor alternator described in Vol. I. page 124, the poles were shown staggered; this practice has been followed by Ganz and Fynn in order to use a single-coil armature winding.

The general formula for voltage of inductor alternators may be given as follows: $E = kPZ{\sim}Nt\,n\,10^{-6}$, wherein

E = induced E.M.F. per phase
Z = armature flux per pole.
Nt = number of conductors in series per phase.
k = a constant for E.M.F.
$\sim$ = frequency.
n = speed per minute.
$\sim = \frac{n \times P}{60}$
P = number of poles.

$k = 2.2$ in most cases, it is evident that for inductor machines Nt must be taken as being *half* the total number of conductors in series per phase. The disadvantage of having idle copper in the armatures of inductor machines is balanced by the gain which results from the non-reversal of the magnetic flux in the iron, for with the same core loss a much greater flux density can be employed. On account of the complicated flux distribution in the armature iron, the flux density cannot be doubled, but can usually be increased considerably; the value for the permissible armature flux density will usually lie between 70,000 and 80,000 lines per square inch at fifty cycles.

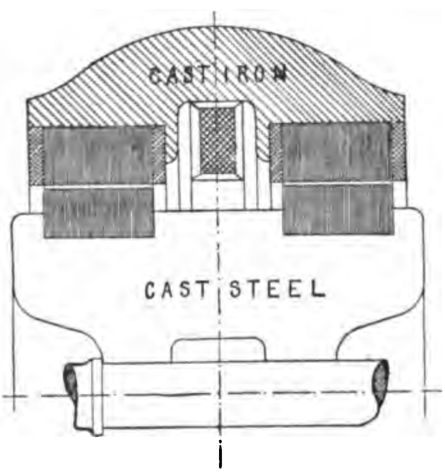
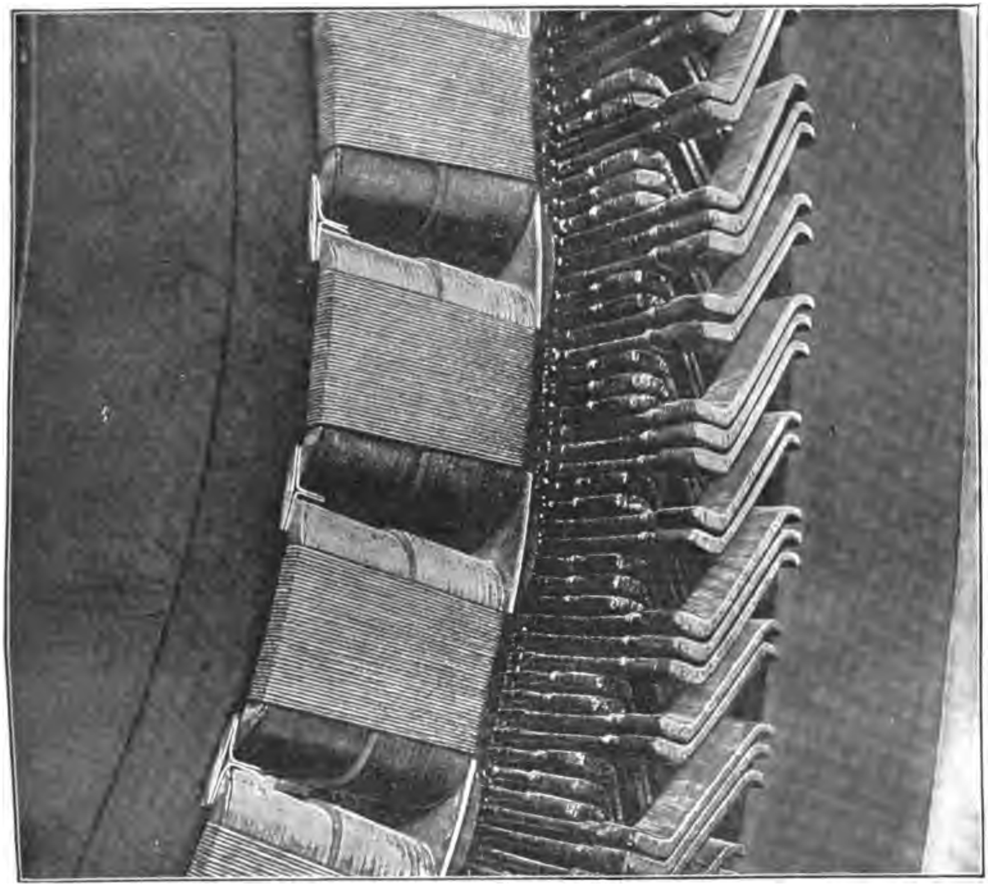


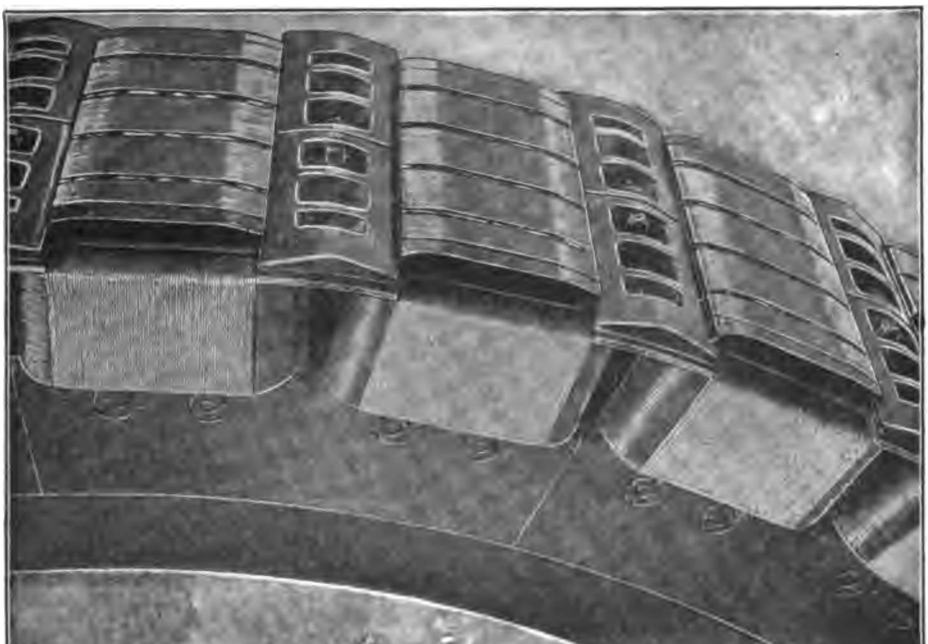
FIG. 165

The inductor machine requires less exciting than others, but owing to reactive effects of leakage of the magnetic fields, especially on inductive loads, it is not a successful type for large power work, and I agree with the following summing up of Mr. Eborall:—

"While holding the opinion that the inductor type of polyphase generator is unsuitable for power work in general, I consider that the type presents some distinct advantages for direct connection to steam-turbines, and that for this work a well-designed inductor machine is the best to employ. In such a case, the absence of sliding contacts and rotating windings (either field or armature)



ALTERNATOR ARMATURE WINDING



PORTION OF ROTATING FIELD MAGNET, SHOWING POLE FACES AND COILS AND PART OF FIXED ARMATURE. (WESTINGHOUSE CO.)

Ferranti Copper Alternator Armature

constitutes a solid advantage, while the very high speed of rotation will go far to ensure a satisfactory performance, even on an inductive load."

The Westinghouse rotating field, with alternating NS NS poles, has been referred to already. By Mr. Eborall's permission I reproduce sketches of a design for a 760 K.W. alternator designed by Mr. Heyland, for 2200 volts per phase, 94 revolutions, frequency 50; the armature is star-wound, and therefore full load current in each phase is 200 amperes.

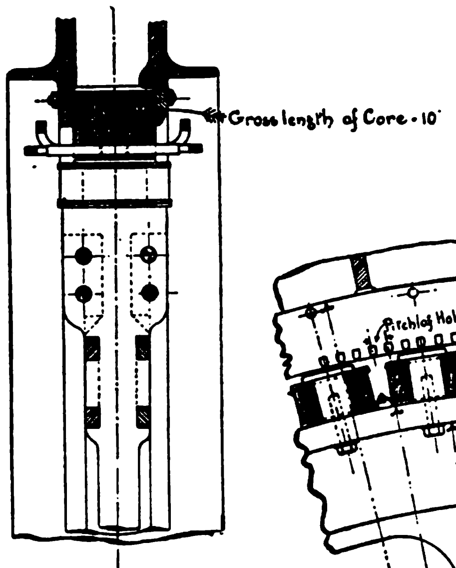


FIG. 167

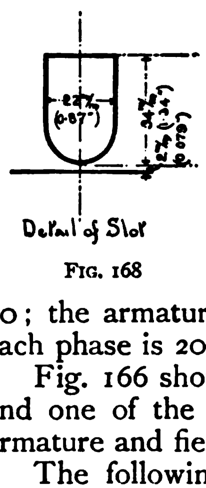


FIG. 168

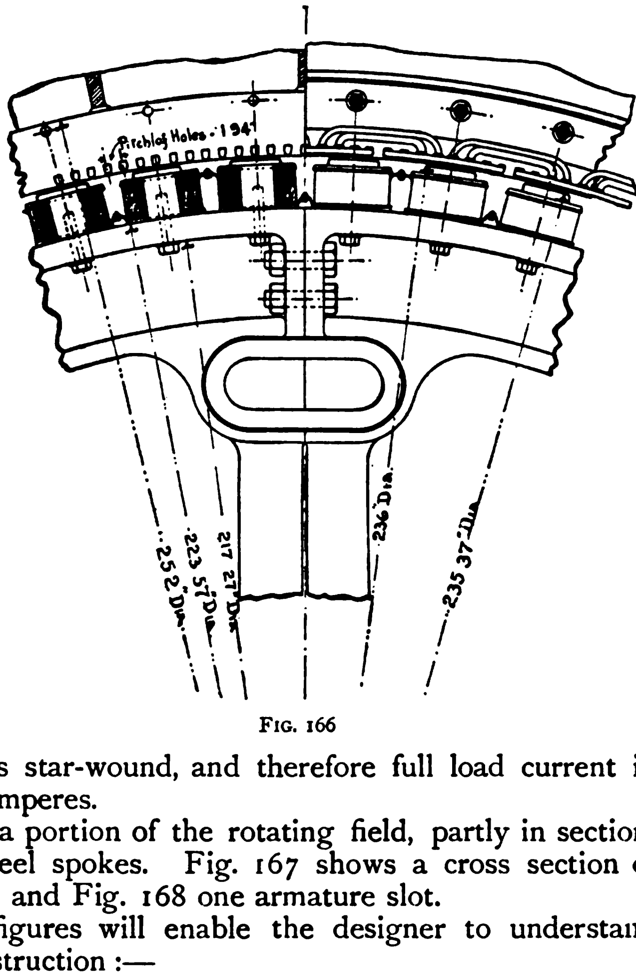


FIG. 166

Fig. 166 shows a portion of the rotating field, partly in section, and one of the wheel spokes. Fig. 167 shows a cross section of armature and field; and Fig. 168 one armature slot.

The following figures will enable the designer to understand fully the whole construction :—

GENERAL DATA OF E. AND H. THREE-PHASE GENERATOR.
TYPE G T 700.

Armature:—

External diameter of core	252″
Internal „ „	236″
Gross length of core	10″

Allowance for paper insulation	10 per cent.
Number and width of air-ducts	2 × 0.4′
Total number of holes	384
Number of stranded wires per hole	6
Arrangement of wires in hole	3 in series, 2 in parallel, each wire 0.222″ in diam.
Number of conductors in series per phase (Z)	384
Section of each conductor	2 × 0.0495″
Resistance per phase, warm	0.13 ohm
Number of teeth under one pole shoe	3
Field System :—	
Material of yoke, poles, and pole shoes	Cast steel
Overall diameter	235.37″
Number of poles	64
Section of each (oval) pole core	32.5 sq. in.
Dimensions of pole shoes	(5.9 × 10)″
Allowance for spread of flux	10 per cent.
Pitch of poles at face of shoes	11.57″
Number of turns in series per pole	50
Dimensions of field conductor (copper ribbon)	4.18″ × 0.0315″
Resistance of field circuit, warm	0.7 ohm
General :—	
Length of air-gap (iron to iron)	0.315″
Value of E.M.F. factor (k)	2.12
Value of leakage coefficient at no load (v)	1.15

The actual full load fall of pressure per phase of this generator is about 5½ per cent. for a power-factor of 100 per cent., and about 14 per cent. for a power-factor of 80 per cent. at constant speed and

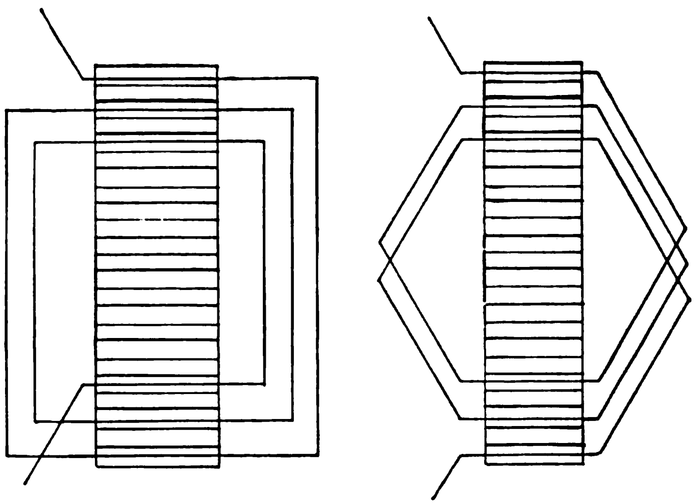


FIG. 169

excitation; these figures will therefore check the calculation. This machine is noteworthy in respect of its very small field-magnet leakage, a result principally due to the exceedingly short length of

the pole cores and the small length of the armature core compared with its diameter. These features of design, in conjunction with the very high magnetic saturation in the pole cores (another special feature), make the value of the pressure drop remarkably small for highly inductive loads.

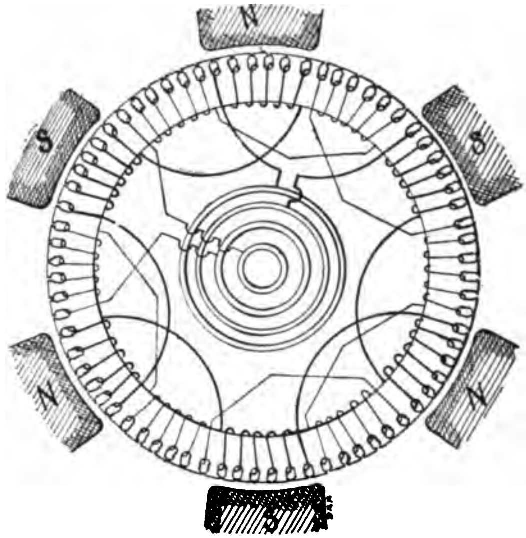


Fig. 170

The armatures of alternators are very much the same as the armatures of wound rotors, and the same principles apply to both. In the single-phase generator we have coils and spaces alternately, so that the coils as they revolve pass from one pole through a space of no field to the maximum field, thus giving a maximum and minimum induction to produce the alternating E.M.F. If we fill the spaces between the armature coils, with other coils in a separate series, that is, to cover the armature completely with two series of coils; it is clear that when the current or E.M.F. in the one series is at its maximum value the E.M.F. in the other series will be at its minimum value, and so on all the time of working, so that we get the two circuits with induced E.M.F. in each differing from the other by one-fourth of a complete period = $\frac{T}{4}$. Two currents or E.M.F.'s so differing have been called two-phase currents. A diagram of the winding is shown in Fig. 171. The thick black lines

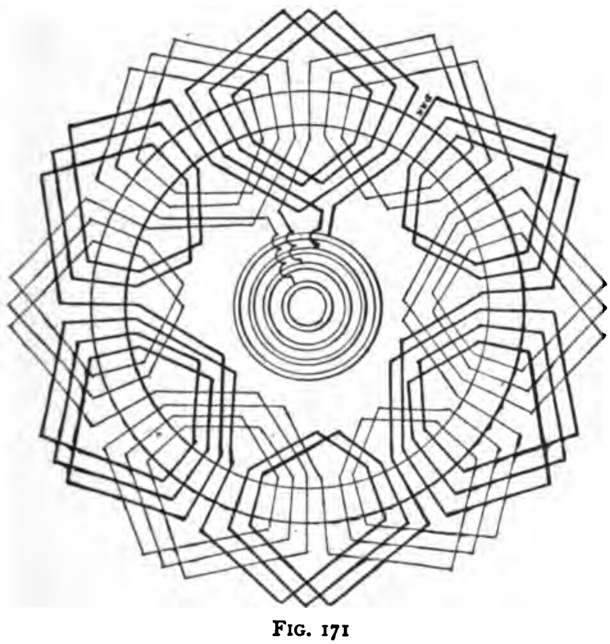


Fig. 171

are all one series, and the thin lines all another series. In Fig. 170 a ring winding is shown with six poles and twelve coils. For two phases we must have double the number of coils to poles, so that one set is under full excitation under the poles while the second set are passing in the space between the poles at zero induction. This ring form is simple but bad in design, for the circuit of the coils is long round the iron core, and allows of a great deal of magnetic leakage. A drum form is better, and is shown in diagram in Fig. 171. Here we have twelve coils again in the two series. These would be laid in series in slots, two series of six coils each, and they may be wound according to the styles shown in Fig. 169.

Fig. 172 represents a portion of an outer fixed armature with the coils in place for two phases.

For three phases the ring winding is again the simplest to show its principles. Fig. 173 shows a six-pole machine. The fundamental idea is to arrange three sets of coils; that, in this case, would be eighteen coils —six coils in three series —or, as it is usually put, three coils per phase. The thick lines are for one phase, the thin lines for another phase, and the dotted thin line for the third phase. In the position shown, the thick black lines are all right under the three north poles, and their E.M.F. at a maximum; the other three coils of thin black lines are half way under the S-poles, and the induction increasing; while the third set of thin dotted lines are half way under the south poles, and decreasing towards zero. In this case, then, when one series is at a maximum E.M.F., the other two are at half their maximum value, the one increasing in pressure and the other decreasing.

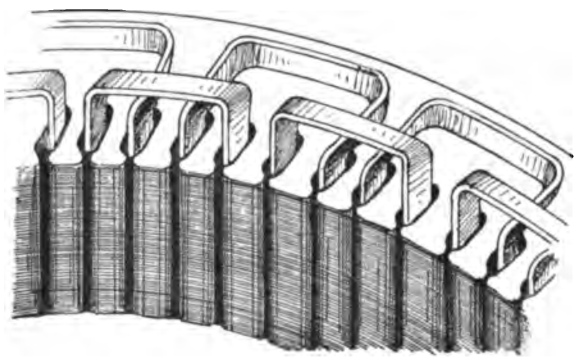


FIG. 172

A drum winding is shown in Fig. 174 for six poles, three coils per phase, and four turns per coil. If this were a bar winding, 72 slots would be required, $6 \times 3 \times 4 = 72$.

There is a multitude of different windings possible, but these will give as good an idea as any others of the principles. It would seem as if all alternators should be polyphase whether polyphase working is used or not. For a polyphase, say a two-phase generator can be used to feed two separate single-phase circuits. with the same size of alternator nearly twice the output can be had in this

way. I advocated this point fifteen years ago, but only quite recently has it been recognised.

One of the full-page Plates represents the fly-wheel alternator of Messrs. Fowler & Co.'s construction, Leeds. The armature, which is fixed, is built up of segmented blocks of thin laminated iron with the coils embedded in slots in the inner periphery, the field poles mounted on the fly-wheel rim.

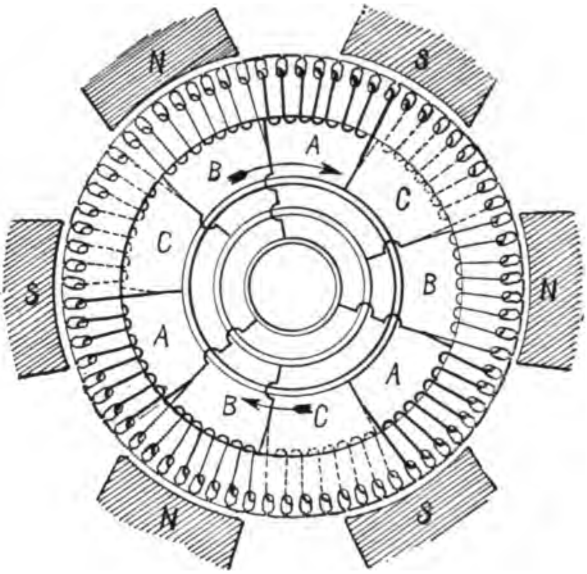


FIG. 173

We have already given the general formula for E.M.F. of single-phase generators as

$$E = K{\backsim}Z\,Nt \div 10^8,$$

wherein K is a constant depending on the breadth of coils and poles. For slot windings such as we have shown, $K = 1.72$; but this value depends much on design, and may be as high as 2.8. In this formula $\backsim$ is frequency, and frequency is found by dividing the revolutions per minute by 60 and multiplying by the number of pairs of poles. Z is the flux per pole; Nt the number of turns or conductors in series in the slots counted all round the armature; if there are more than one phase, each phase is to be treated as a separate armature to find E per phase. In this alternating-current formula we have the same hiatus as that found in the continuous-current

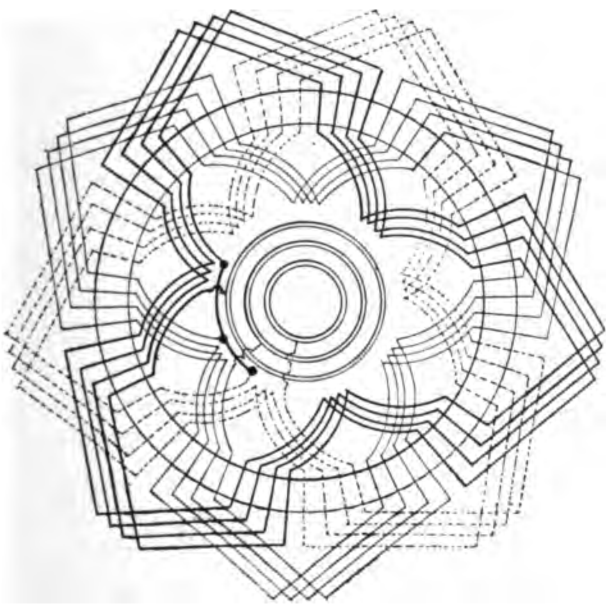


FIG. 174

formula; in fact, it is the same formula, substituting frequency for speed, and K added for the winding effect. Simply to say that $E = k \backsim Z\ Nt \div 10^8$ does not help the designer much in making a start with his design. The question he wants to solve is what is to be the value of $\backsim$ Z and N*t* for a machine for a given output in K.W.

With the alternating-current generator the commutation troubles do not exist, hence we are not restricted to a proportion between the armature ampere turns and the field flux Z. On the other hand, the rule holds good that the stronger the field Z and the smaller N*t* the better in every way the alternator becomes.

We shall not be far wrong in adopting the formula as given for continuous-current machines, $\sqrt{K.W.} \times 250 \times 1000$, and correct this for speed as explained, 1000 being taken as a standard speed.

What the designer has given to start with in addition to this formula is as follows:—

K.W. output	=	K.W.
Terminal pressure	=	E.
And W $\div$ E	=	C total current.
Frequency	=	$\backsim$
Speed per minute	=	*n*.

The number of pairs of poles must be found to give the nearest frequency to that given at the given speed. Suppose the speed given as 240, and frequency 60, then $\frac{240}{60} = 40$ revolutions per second; that is to say, if we had only one pair of poles the frequency would be 4 per second, but we want 60 frequency, hence $\frac{\backsim}{\text{revs. per second}} = P$, or pairs of poles; $\therefore \frac{60}{4} = 15$ pairs of poles, the number required.

Now to proceed farther with a design we must find Z and N*t*.

Required, the winding and dimensions for 100 K.W. alternator of the type shown in plate of Fowler's dynamo alternator. Then if

K.W.	=	100,
E say	=	2000,
Frequency	=	48 per second,
Speed	=	144 per minute $= \frac{144}{60}$ per second $= 2.4 \backsim$
C	=	50 amperes,

then $Z = \sqrt{100} \times 250 \times \sqrt{\frac{1000}{144}} = 17{,}500$ as total flux in Kapp lines. To find the flux per pole we must find the number of poles by our rule, as before—

$$\frac{\text{Frequency}}{\text{Revs. per second}}\ \frac{48}{2.4} = 20 \text{ pairs of poles.}$$

Now if we divide the total flux, 17,500, by 40, the number of poles, we will get the flux per pole—

$$\frac{17,500}{40} = 437 = Z \text{ per pole.}$$

If the poles are good soft iron or steel, their section may be found by dividing this flux by 15. $\frac{437}{15} = 30$ square inches approximately, say 6×5 inches, or 10×3 inches, the section of each pole on the fly-wheel.

Now we have found the poles and the flux Z, we proceed with the design to find N*t*, the turns of wire; and here the constant K comes in. In a machine like the one we are calculating K may be taken as equal to 2. Then

$$Nt = \frac{E \times 10^8}{2 \times Z \times \sim \times 60} = \frac{2000 \times 10^8}{2 \times 437 \times 48 \times 60} = 800$$

armature wires counted all round.

There would be 40 coils, each filling half of the space on each side of a pole, or, taking two sides of a coil as filling one space, we get $\frac{800}{40} = 20$ wires, or 10 turns of wire in each armature coil.

A stranded cotton-covered conductor of 37 No. 20 S.W.G. copper wires would carry this current easily.

It is often thought necessary to wind the armature and connect it across at opposite diameters, so that points of greatest P.D. are far apart.

It will now be seen that the formula for finding Z is equally useful with alternating-current designs, and that we can by using it simplify the calculation. I have used Kapp or English lines to save the large numbers required by the C.G.S. The student, however, can easily convert from the one to the other. In the formula for finding N*t* I have used 437 as Z in Kapp lines; but for C.G.S. this value would be multiplied by 6000, and I have multiplied $\sim$ by 60 to bring it to minutes in the calculation.

Those who wish to adhere to C.G.S. units can begin with a formula to find Z in C.G.S. thus:—

$$Z = \sqrt{K.W.} \times 250 \times \sqrt{\frac{1000}{n}} \times 6000 \div 40 \text{ for one pole.}$$

$$\text{Then } Nt = \frac{2000 \times 10^8}{2 \times Z \times \sim} = \frac{2000 \times 10^8}{2 \times 2,625,000 \times 48} = 800$$

approximately, the C.G.S. line being $\frac{1}{6000}$ of a Kapp line.

If preferred for cost's sake, the constant may be made of less value than 250 in the formula for finding Z. The machine would be cheaper if the constant used were 150 in value, for then the magnets and the armature core would be of less weight; but the armature coils would require to have the number of turns increased in proportion, and that increases the drop in pressure due both to ohmic and impedance resistances.

The induction of the armature cores must be low to get the best

efficiency and quiet working, not more than 6.5 or 6000 C.G.S. lines in the body and 10,000 in the teeth.

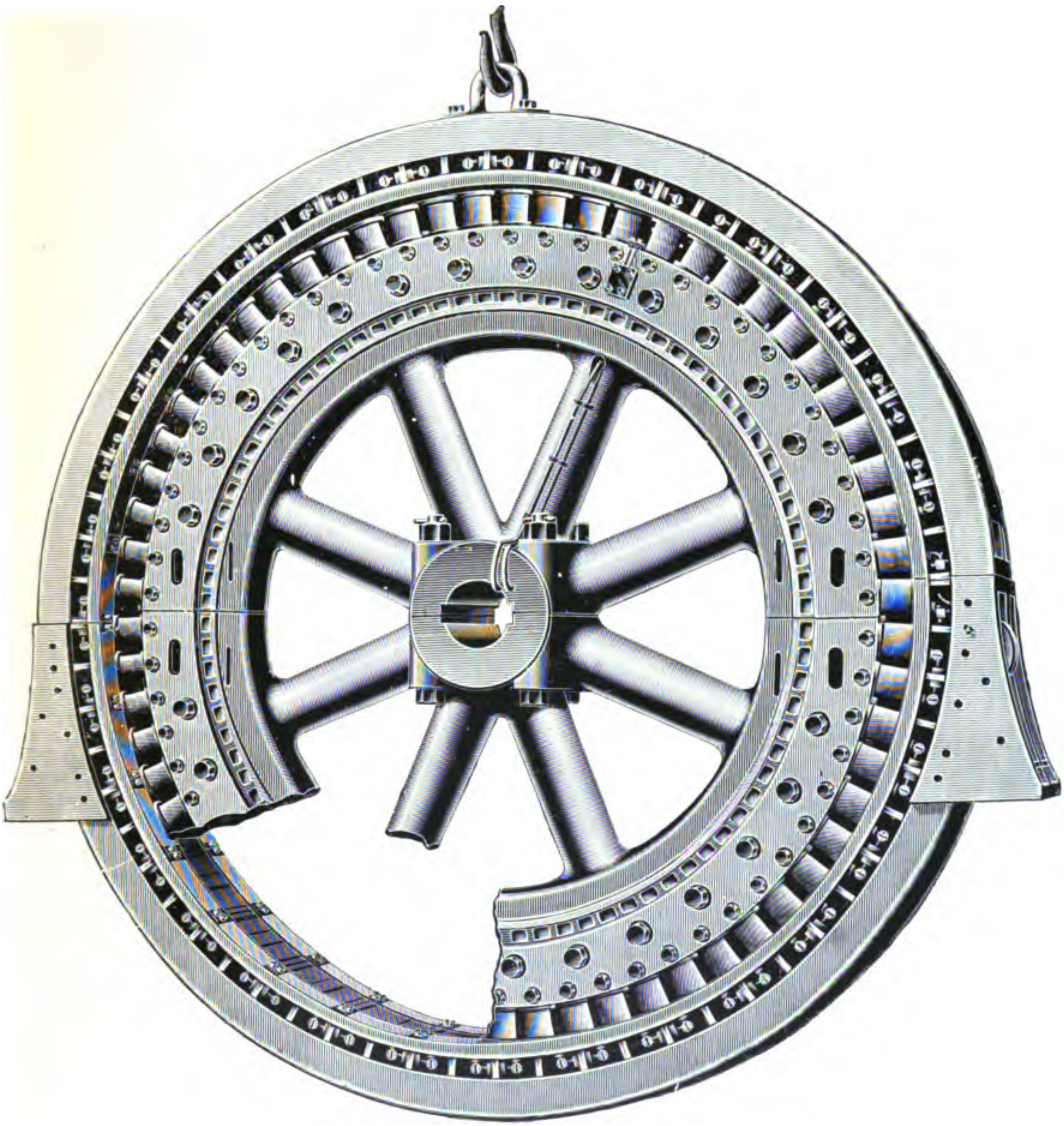
The question of frequency is and always was one of prime importance, Yet the engineers, in whose power it was to settle such a question, gave it no attention, and therefore, as a natural result, the frequencies in practice are mostly blunders. For electric lighting any frequency above 30 will suffice; but for power work the lower it is the better down to 15; here again the schemes for distributing electrical energy in bulk are destined to meet with trouble between the two.

It used to be said that there is only one brand of electricity; but that is not so now, for a current of one frequency is not equally good for all purposes. And however we may transform pressures we cannot profitably transform frequencies.

The machine calculated out has a fixed armature. This makes no difference in calculation; the armature might be rotated. One of this type is shown in Fig. 176 completely wound.

FIG. 175.—Rotating Field Core

We have seen that M. Thury has succeeded in reversing the system of transmitting electrical energy and in distributing it, beginning with continuous current. Such a system could never have been introduced in this country; our so-called experts, finding it beyond their experience, would have none of it. By-and-by, however, when it is all quite clear to them, it will be slavishly copied. Again, we have another departure from ancient practice, made by the Westinghouse Company, in applying alternating single current to electric traction. The invention consists of three elements: 1st, a single-phase motor, working the same as a continuous-current series motor; 2nd, the use of a frequency as low as 30; 3rd, the use of a controller, consisting of a transformer with its secondary movable. Broadly considered, these are not novelties; but, when we come to consider the details, we find that many points had to be carefully worked out to make such a system a success. The main question in such a system centres in the motor. If we can get an alternating motor with all the characteristics of the continuous-current motor, with its field and armature in series, the problem of working long lines of railways by electricity is solved, and another great advance made. Before the introduction of the polyphase motor, ordinary series continuous-current motors were used with single-phase currents. That they did not come more into use was due, as usual, to the blundering of engineers, not to any difficulty in the motors themselves. Firstly, the frequencies in practice were



Rotating Field and Fixed Armature of Single-Phase Fly-Wheel Alternator
(John Fowler & Co., Leeds)

all too high, and are so still; secondly, no manufacturer in this country would spend money in developing them—he waits to follow the foreign leading. It will no doubt receive great attention now that the Westinghouse money and brains have shown how to do it successfully.

Any series continuous-current motor with a well-laminated field and armature will work as a motor fairly well on a single-phase

FIG. 176.—Rotating Armature

circuit. If the frequency is over 30 its efficiency is very low, and a large motor gives comparatively small power; but if we come down to frequencies of from 15 to 30, it becomes quite practicable and efficient.

Again, the makers of these early motors to be worked on alternating current did not understand the laws and rules for designing them to get the best results; that, however, is all changed now. The knowledge and experience gained with induction motors are applicable to this motor also. And so is the knowledge of continuous-current motors more extensive than it was when these early motors were tried. It is therefore senseless criticism to say that a

laminated series motor is old and was abandoned years ago; these old devices have a habit of bobbing up to confound the shallow arguments of such criticism. In 1892 Mr. H. F. Joel patented such series motors, and also shunt motors No. 18,847; Fig. 177 shows three forms of his laminated magnets. Then Messrs. O. T. Blatty and M. Deri follow with Patent 6050, 1893. Fig. 178 is a diagram of this invention, which relates to alternating-current motors which are constructed similarly to ordinary continuous-current dynamos, with the exception that the armature and field-magnet cores are made of divided iron. In order to prevent the sparking due to the short-circuiting of the armature coils by the brushes, the junctions b^1, b^2, &c., of these coils are not connected directly to the commutator plates c^1, c^2, &c., but through intermediate pieces w^1, w^2, having a suitable resistance or self-induction, or both combined. The intermediate pieces are wound upon a core a, which may either be an independent core or the armature core itself, adjacent coils being wound in opposite directions. Their resistance is such that a current will circulate in the section short-circuited by the brush, which is nearly equal to the working current in the other sections.

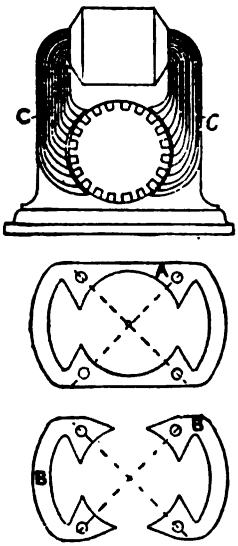


FIG. 177

Then follows Messrs. Hutin and Leblanc's Patent 12,139, 1893. The object is to arrange that alternating-current motors shall be self-starting, and be free from sparking and self-induction. The sections of the armature and commutator are connected in two groups, the odd numbers in one group, and the even in a second. The brushes are made of such a thickness that the sections cannot be short-circuited, and are also formed with supplementary strips connected to the brush through resistances. Fig. 179 shows a side elevation of one form. The field magnets consist of a ring R having a series of poles a^1, a^2, a^3, a^4 projecting towards the centre and wound in series. The poles have enlarged ends nearly touching the armature E as shown. Between these poles are supplementary poles b^1, b^2, b^3, b^4, separated from the main poles by copper strips D^1, D^2, D^3, D^4 forming magnetic shields. These supplementary poles are wound in series with the main poles.

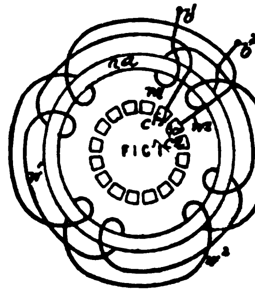


FIG. 178

Then Kingdon, in Patent 14,664, 1893, relates to alternating-

current motors, and particularly to means for preventing sparking at the commutator. The commutator is constructed with thick plates of mica or other insulator between the metallic segments, and instead of single brushes there are employed groups of two or more brushes B^1, B^2, and B^3, B^4, the members of each group being insulated from each other and connected together through coils F^1, F^2, and F^3, F^4, which may be wound on the field magnets, as shown in Fig. 180.

There were earlier motors on this principle than those quoted here. Some series laminated motors were made in Glasgow and worked by the author in 1888. However, as we did not get satisfactory results on the supply circuits at 60 to 120 frequency, we gave up making them.

In Vol. I. page 131, a commutator motor is shown of Professor

FIG. 179

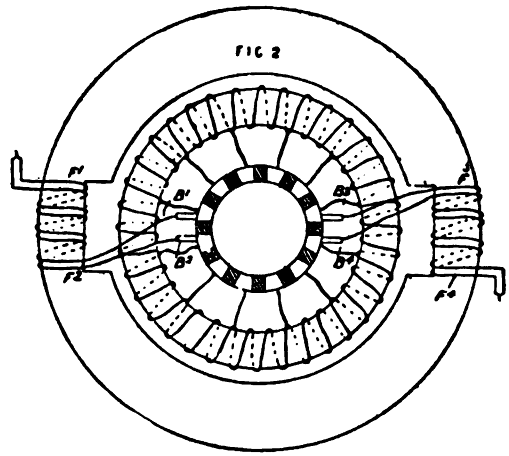


FIG. 180

E. Thomson's design. This works as an induction motor with short-circuited brushes. The field-magnet design is bad, for it is one which leaks very badly. A better design for magnets is that shown in Figs. 181 and 182.

With a closed-circuit winding on the armature there is great induction in the coils coming under or near the commutation line, and many of these proposals of the inventors in these early days only made matters worse in endeavouring to overcome this induction trouble.

A series wound motor with laminated field has three opposing forces against the working pressure—firstly, ohmic resistance; secondly, self-induction; thirdly, counter E.M.F. when running as with a continuous current. Such motors are necessarily worked at low magnetic induction in the field and armature. Neglecting the ohmic resistance, which is comparatively insignificant, the

power such a motor can develop will be a maximum if the volts required to overcome its self-induction equal the volts required to overcome its counter E.M.F. But with high frequency the E.M.F. of self-induction is very much greater than any counter E.M.F. that could be developed. At even a very high speed it is quite clear that low frequency must be used; low frequency and high speed is the successful combination. If we tested the motor on continuous current, we could find its counter E.M.F. as a motor.

The self-induction increases as the current increases, and is the product of a constant into the current.

The pressure applied to the motor when working alternating should be about double that required at same speed and load when working continuous.

The new Westinghouse laminated series motor for alternating

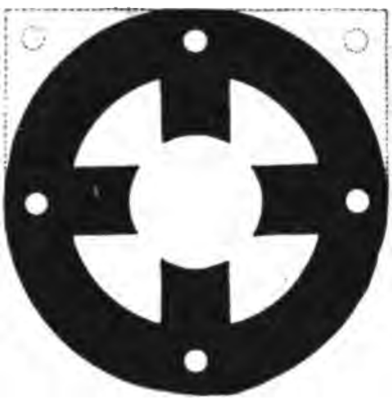


FIG. 181

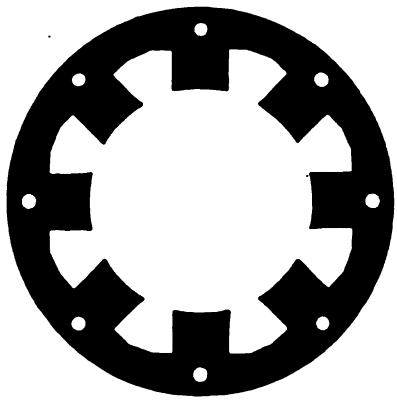


FIG. 182

current is not yet very fully described. The most that can at present be learned about it is that it is much the same as some very early motors, but with some special devices for reducing sparking due to the induced current in the coils short-circuited at the brushes. The following description is given by Mr. Lamme, the inventor of the motor, in a paper read in America recently :—

The motors on the car are all of the straight series type. The armature and fields being connected in series, the entire current of the field passes through the armature as in ordinary series direct-current motors. The motor has eight poles, and the speed is approximately 700 revolutions at 220 volts. The general construction is similar to that of a direct-current motor, but the field core is laminated throughout, this being necessary on account of the alternating magnetic fluid. There are eight field coils wound with copper strip, and all connected permanently in parallel. The parallel arrangement of field coils assists in

equalising the field strength in the different poles, due to the balancing action of alternating circuits in parallel. This arrangement is not really necessary, but it possesses some advantages and therefore has been used. With equal magnetic strength in the poles, the magnetic pull is equalised even with the armature out of centre.

The armature is similar in general construction to that of a direct-current motor. The fundamental difficulty in the operation of a commutating type of motor on single-phase alternating current lies in the sparking at the brushes. The working current passing through the motor should be practically no more difficult to commutate than an equal direct current, and it is not this current which gives trouble. The real source of trouble is found in a local or secondary current set up in any coil, the two ends of which are momentarily short-circuited by a brush. This coil encloses the alternating magnetic field, and thus becomes a secondary circuit, of which the field coil forms the primary. In the motors of the Washington, Baltimore, and Annapolis Railway, this commutation difficulty has been overcome, by so constructing the motor that the secondary or short-circuit current in the armature coil is small, and the commutating conditions so nearly perfect, that the combined working and secondary currents can be commutated without sparking. This condition being obtained, the motor operates like a direct-current machine, and will give no more trouble at the commutator than ordinary direct-current railway motors. Experience covering a considerable period in the operation of motors of 100 H.P. capacity indicates that no trouble need be feared at the commutator.

An extended series of tests was made with these motors at the Westinghouse shops at Pittsburg, both in the testing room and under a car. Fig. 183 shows curves of the speed, torque, efficiency, and power factor plotted from data derived from brake tests.

It should be noted that the efficiency is good, being very nearly equal to that of high-class direct-current motors. The power factor, as shown in these curves, is highest at light loads and decreases with the load. This is due to the fact that the power developed increases approximately in proportion to the current, while the wattless component of the input increases practically as the square of the current. The curve indicates that the average power factor will be good. The calculations for the Washington, Baltimore, and Annapolis Railway show that the average power factor of the motors will be approximately 86 per cent.

The average efficiency of these motors and controllers will be much higher during starting and accelerating than that of corresponding direct-current equipments, as C^2R losses are avoided.

When running at normal full speed, however, the efficiency will be slightly less than with direct-current. This is due to the fact that the alternating-current motor efficiency is slightly lower than the direct-current, and in addition there are losses in the transformer and the regulator. The alternating-current outfits are somewhat heavier than the direct-current, thus requiring some extra power, both in accelerating and at full speed. Therefore, for infrequent stops the direct-current car equipment is more efficient than the

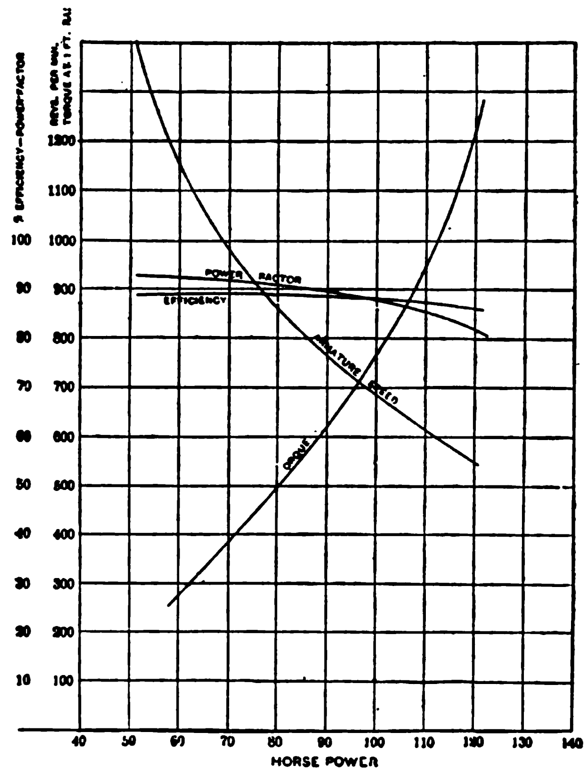


FIG. 183

alternating-current, but for frequent stops the alternating-current shows the better efficiency. Tests on the East Pittsburg track verified this conclusion.

There are more methods of solving the problems connected with series motors for alternating working, as we shall see later on. They are only useful for electric railways at present, but may be also used for long distance distribution of power from one point to another point, in the same way as has been frequently carried out with two series machines for continuous current.

It has long been well known that two series machines form an excellent self-regulating combination for transmitting power from

one place to another at nearly constant speed. For this purpose the generator is constructed to give a terminal pressure somewhat higher than the machine to be used as a motor—about 10 per cent more. If the generator is then driven from a shaft or engine running at constant speed, the motor will run at nearly constant speed at all loads, and the current passed from one to the other will vary as the load varies, and, of course, so also will the pressure at the terminals.

When the load is thrown off the motor it increases slightly in speed, and its counter E.M.F. rises and dams back the current from the generator; and thus the fields are both weakened so that the pressure also falls, conversely, when the load is thrown on, the motor falls in speed, and its counter pressure falls and allows more current to pass, thus strengthening the field and armature simultaneously.

We shall see that this system is useful in many cases both with alternating and continuous currents.

The rotary converter construction is not much different from that of a polyphase machine; but it is better to design it as a continuous-current multipolar generator, with due regard to the number of poles to suit the frequency of the alternating-current side and the speed. If the given speed is not such that an even number will give it at the frequency, then the speed must be altered to fit it.

For simplicity, we may take a rotary convertor as an example to convert a single alternating current to continuous frequency $= 60$ per second; speed to be near 400 per minute, or $\frac{400}{60}$ 6.6 per second. Now, the $\frac{\text{frequency}}{\text{speed per second}}$ must be a whole number, and $\frac{60}{6 \cdot 6}$ would not give this. We would take the nearest number 6 for the speed per second, hence the speed nearest 400 would be 360, and pairs of poles $\frac{60}{6} = 10$. The machine would then be designed as a multipolar continuous-current machine with 10 pairs of poles.

If the speed given were 900, or 15 per second, then $\frac{60}{15} = 4$ pairs of poles. The machine would be an eight-polar continuous-current dynamo, and would be calculated as such, whether single, two, or three phase, the different phases being obtained by contacts at different points in the winding.

The diagram, Fig. 184, shows the principles of construction of such a machine. For simplicity a gramme ring winding is shown, but a slot-wound former-coil drum would be preferable in practice. When these machines require starting on alternating current they have a small induction motor fitted on one end of the shaft for that purpose, as they are not satisfactory self-starters with alternating

current. But when used as convertors from continuous to alternating they, of course, start readily as continuous-current motors.

When used to convert from alternating to continuous, the continuous current delivered has a lower pressure than the alternating pressure, so that a booster is sometimes also coupled on to the shaft.

The small induction motor runs the speed up to synchronism, for the rotary convertor is a synchronous alternating motor when converting from alternating to continuous current, and runs steadily in synchronism.

When the rotary is driven by direct current it, of course, follows

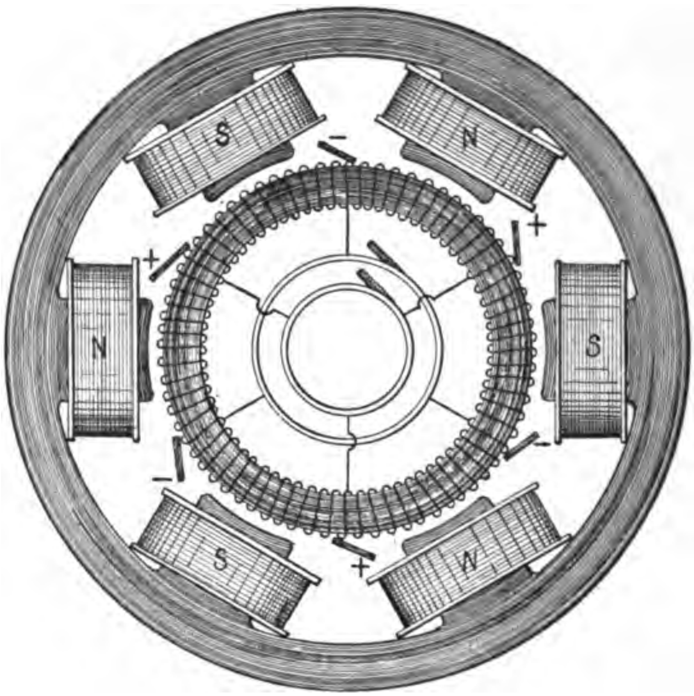


FIG. 184

the law of an ordinary continuous-current motor, and its speed is equal

$$\frac{E}{B} \cdot \frac{60 \times 10^8}{P.\ Nt}$$

where E is volt supply, B induction through armature, P number of poles, Nt armature conductors counted all round. In fact, the speed depends on E and B and armature reaction, so that it is not quite so simple a process as would be supposed to convert from continuous to alternating by these machines.

For the currents on the alternating side shift in phase on an inductive load, thus causing enormous armature reactions, causing large changes in speed and frequency.

Mr. Salter, of the South Lancashire Tramways, has given an account of his remedy for this trouble in the *Electrical Review* of London as follows:—

"The method employed for overcoming the instability in the speed of the rotary when driven as a direct-current motor is to excite the rotary by means of a small generator, which is driven from the rotary itself. Tappings are taken from the three-phase side of the rotary to a small induction motor, which is directly connected to a small continuous-current generator. This generator works low down on the characteristic curve, and is unsaturated at the normal electromotive force. Any change in the speed of the rotary, therefore, causes a much greater change in the electromotive force of the exciter, and this varies the field of the rotary, and keeps the alternations constant independent of the nature or amount of the

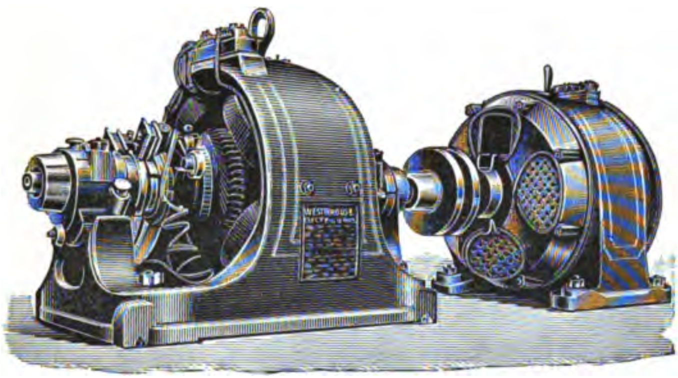


FIG. 185

load. The small exciter set is shown in Fig. 185. The exciter generator has a normal 220 volts with a current of 6 amperes. Arrangements had to be made for putting the rotary field coils in two parallel sets when excited in this manner.

"The rotary was frequently run under these conditions, and with very satisfactory results. On the alternating side it was connected to the low-tension side of the transformers in the generating station, the high-tension side of the transformers being connected to the sub-station feeders. At the sub-station the current was transformed down, and, by means of a second rotary converter at the sub-station, the lines in the vicinity were supplied with direct current. The system was capable of working twenty cars without hunting, and also of working in parallel with a second rotary converter sub-station operated by the main three-phase generator. For starting the rotary up as a direct-current motor, the series coils were cut out and the machine run as a shunt-wound motor. It was found that when operated as a shunt motor, and working in parallel with the alter-

nator supplying the same feeders, the rotary frequently fell out of step. On reversing the series coils, however, the rotary kept perfectly in step with the main generator.

"It will be observed what an important part the series coils play in maintaining the stability of the system and preventing hunting. The method of regulation frequently employed in connection with rotary converter equipments is to insert self-induction between the slip rings and the transformers, and by this means the impressed pressure, and consequently the direct-current pressure, is varied. In the equipment referred to, however, no such arrangement was adopted, the transformers being designed with large magnetic leakage, and the rotary being so designed that the series coils affected the excitation to the extent necessary to vary the impressed pressure so as to maintain stability. As explained above, the series excitation was a little too great for perfect parallel running with the direct-current generators. When generating alternating currents, however, and although being separately excited as a shunt-wound motor by means of an arrangement designed to increase the excitation in proportion as the speed increased, on account of lagging currents, the rotary did not maintain absolute synchronism unless the series coils were utilised."

From all this it will be seen that rotary convertors are not remarkable for simplicity, for in this case of actual practice there is quite a collection of modern apparatus, making a somewhat complicated whole. First, we have the rotary itself, not quite so simple as a dynamo; then on one end an induction motor; on the other a booster; and then a motor-generator exciter, with all the attendant switches, fuses, and connections required to operate five machines, or perhaps more correctly six machines.

The conversion from continuous to alternating current to feed into a network of supply is not a problem of much commercial importance, as the necessity seldom arises; but it could be much simplified by dismissing the rotary, with its induction motor and booster, and using a larger exciting motor generator, Fig. 185—that is, a combined continuous-current generator, compound wound with an alternator, both properly calculated for the pressures, speeds, and frequency to be handled. By then working the series winding on the continuous-current field magnets reversed—that is, to weaken the field as the load increases when working as a motor driving the alternator—the alternator will keep step perfectly, for the speed of the motor can be kept constant under these conditions.

The induction motor would still be required to start up on alternating current to be converted to continuous.

Broadly considered, motor generators or rotary convertors, whether for continuous or alternating current, are better in every

way when built of two separate machines, but the cost is considerably higher.

We have briefly alluded to the mixed systems used in tramway working, using alternating current for transmission and continuous current for the trolley, with rotary convertors between the two. In city tramways it is a very questionable practice. The distances are not great—in any case, need not be over ten or fifteen miles. Continuous-current high-pressure transmission, with continuous-current motor generators, would be much simpler and more efficient up to 4000 volts. Beyond that pressure alternating may have the advantage in step up and down stationary transformers.

It is now necessary to refer to the running of alternators in parallel. A machine to run in parallel successfully must have some

FIG. 186

self-induction. Hence alternators with iron-cored armatures are now almost universally in use in preference to the copper disc. Alternators with small self-induction must be large, heavy, and expensive, and cannot be safely used on inductive loads in parallel with other generators. Armature reaction and self-induction lowers the terminal pressures, but the lower the armature resistance the better for parallel working. Two alternators of different voltages can be safely thrown into parallel. The pressure produced will then be intermediate between the pressures given by each. There are many instruments and methods for indicating to an attendant when an alternator is in step or synchronises with another with which it is to be coupled in parallel. The Schuckert optical method is given here as it is interesting also as showing the different phase changes, resembling the beats in sounds from two sources of sound nearly in unison. Fig. 186 shows the front of the instrument.

Optical Synchronisers

The principle involved in the apparatus described is applicable either for single or multiphase alternate-current supply.

As, however, three-phase working finds by far the most general employment, the following description refers to the arrangement for this method of supply, and the reader can easily modify the same for use with two or single-phase current.

The three-phase synchroniser consists of a set of glow lamps arranged in a circle or in a straight line and connected to secondary windings of a three-phase transformer. Each of the three primary coils of the latter is connected between a bus bar and a terminal of the machine to be paralleled, as shown in Fig. 187.

The arrangement of the primary coils, as also the connection of

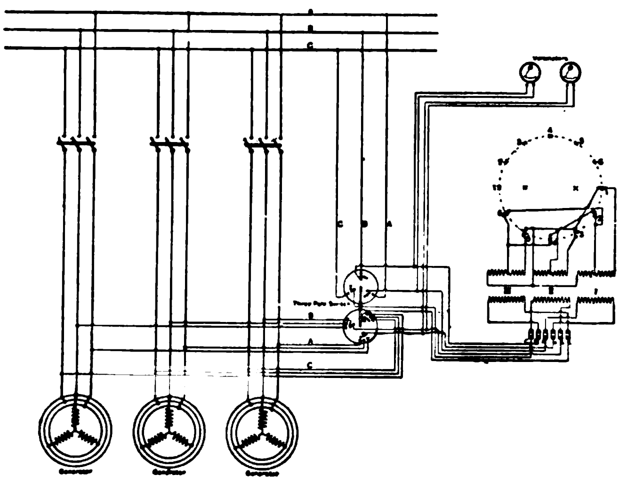


FIG. 187

the glow lamps to the star-connected secondary coils, can be seen in Fig. 187.

For simplicity, only half the glow lamps have been shown, the remainder being one in parallel with each of the lamps shown. By means of the lamp connections each secondary is divided into two parts. The point of connection is so chosen that the number of windings between this point and the common point of connection of the three coils bears to the total number in the coil, the ratio of $\frac{\sin 30^\circ}{\sin 60^\circ} = \frac{1}{\sqrt{3}}$

The pressure in the primary coils of the transformer is the geometrical difference of the component parts of the pressure delivered by the bus bars and the terminals of the machine. The pressure in the secondary coils is proportional to that in the primary, and is the same if the number of windings in both are the same, which, for simplicity, will be assumed to be the case.

Should the machines already running and the machine to be connected be already in parallel—which does not necessarily involve their being in phase—the distribution of pressure over all three coils remains steadily the same, and consequently the lamps connected to the corresponding secondaries will also be under the same steady pressure.

The distribution of pressure to the individual lamps is, however, different. Certain lamps receive a maximum pressure and burn brightly, others less, and with some the pressure is *nil*, and they do not burn at all.

This distribution of pressure between the lamps depends on the phase difference between the pressure components of the primaries.

If the machines are in phase, the pressure components of the three coils are represented in Fig. 188. If the pressure between one of the bus bars (respectively machine terminals) and the neutral point is denoted by "e," then the pressure

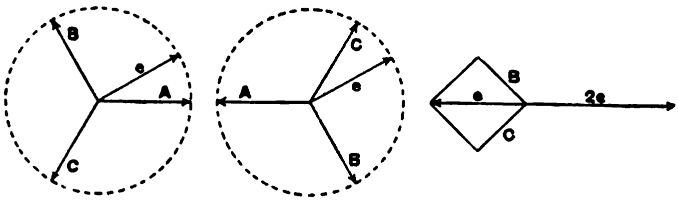


Fig. 188

in coil I. will be 0, while that in coils II. and III. amounts to $e\sqrt{3}$.

From this the pressure on individual lamps will be found to be :—

Lamp 1 $= 0$
Lamps 2 and 6 $e\sqrt{3} \cdot \frac{\sin 30^\circ}{\sin 60^\circ} = e$
Lamps 3 and 5 $e\sqrt{3}$
Lamp 4 $e + e = 2\,e.$

But

$0 = 2\,e \cdot \sin 0^\circ$
$e = 2\,e \times \tfrac{1}{2} = 2e \cdot \sin 30^\circ$
$e\sqrt{3} = 2\,e \cdot \tfrac{1}{2}\sqrt{3} = 2\,e \cdot \sin 60^\circ$
$2\,e = 2\,e \cdot \sin 90^\circ.$

The pressure on each lamp therefore is proportional to the sin of its angle from the line 1 1, and, in consequence, lamp 4 burns brightest, and lamp 1 not at all.

If there is a phase difference of 180° then the pressure

components are shown in Fig. 189, show for coil I. 2 e, for coils II. and III. e, and the pressure on the various lamps will be

Lamp 1 2 e

Lamp 2 and 6 $\frac{2e}{\sqrt{3}}+\frac{e}{\sqrt{3}}=e\sqrt{3}$

Lamp 3 and 5 e

Lamp 4 $e-e=0$.

The lamp pressures stand in the same proportion as before, but the distribution has altered in such a way that the illumination produced has been turned through an angle of 90°.

For phase difference between 0 and 180° the illumination occupies intermediate positions.

Now two alternate-current systems, between which no synchronism exists, may be regarded as being out of phase by a continually varying amount, and consequently, as long as the machine to be connected is out of synchronism with those already running, the illumination of the synchronism will rotate. According

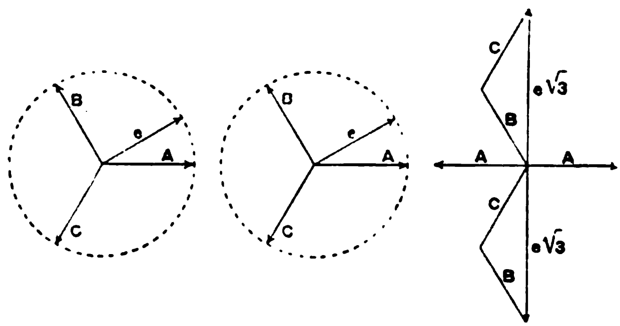


Fig. 189

as its periodicity is two, high or low, the rotation will be in one direction or the other, and the difference in periodicity may be judged by the rapidity of the rotation.

In order to use the apparatus for paralleling machines, one has to wait until the rotating illumination comes to rest, and as soon as it is produced by certain lamps—the phase lamps—the moment of paralleling has arrived.

If it is desired to use the apparatus for single-phase machines, this can be done by employing subsidiary phases produced either by windings of different induction or condensers in the usual manner.

Wilde, in a paper dated 1869, laid down the principles governing the parallel synchronous working of alternators; and not until 1883 was the subject referred to again, when Hopkinson, who had deduced the principles from theory, put his conclusions to tests on the three large De Meritans magneto alternators at the South Foreland.

Wilde first experimented and discovered the principles, and then theorised about them.

It was found that two alternators would run, one as a generator the other as a motor, and that the phases of the generator and motor were opposed; the motor slightly lagging behind in phase

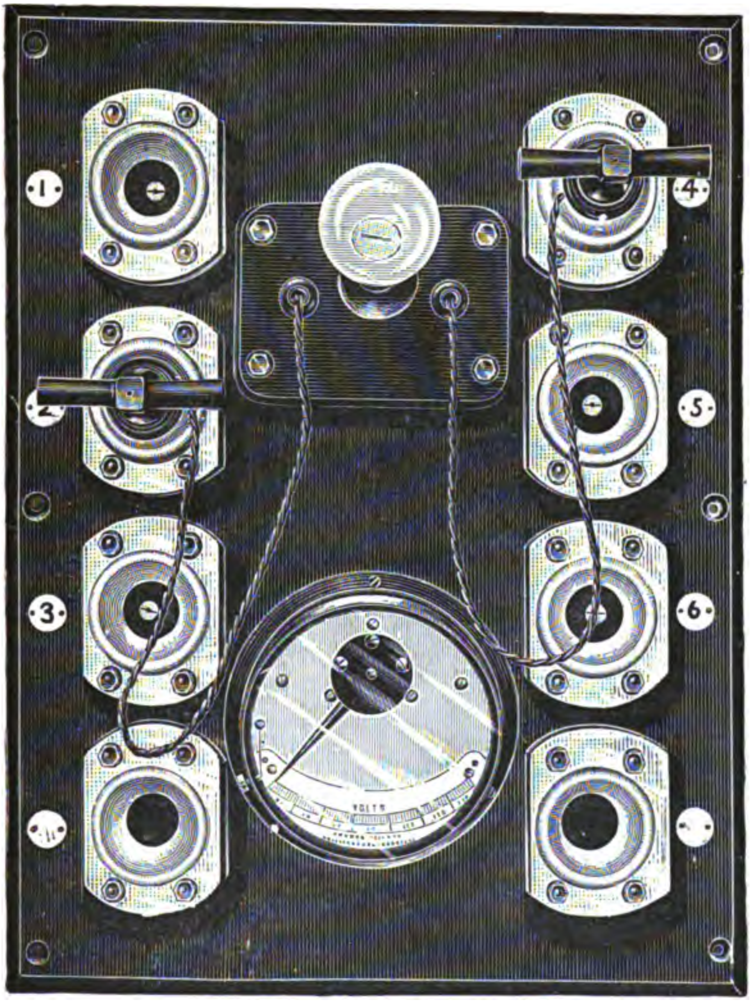


FIG. 190

although strictly synchronous in speed, and that this lag in phase is proportional to the load on the motor.

At a very early date it was realised that alternators would require to run in parallel feeding into common bus bars, and the experiments of Wilde and Hopkinson became of great practical value.

Hopkinson experimented with the De Meritans alternators, which

were magneto machines with a constant field strength. Most alternators now have separatedly excited fields, and these fields can be varied in strength by a resistance or by varying the speed of the exciter. It is most important in parallel running to properly adjust the field strength of the machines so that all may have the same pressure; it is also of great importance in alternating synchronous motors to excite the field up to a point where the armature current is a minimum in value, that is, to the point at which its counter pressure is nearly equal to the working pressure.

The Lowrie Hall synchronising apparatus is shown, in Fig. 190, for six dynamos to be coupled, any two in parallel or all in parallel, for notifying the exact moment when alternate current dynamos are in step with one another. If one alternator at work in the supply station shows, by the ammeter, that its load is approaching or has reached the maximum, so that another machine must be started, a small plug switch places one alternator (by induction through a transformer) in series with the incoming alternator through an ordinary glow lamp and voltmeter (placed in parallel with one another) fixed on the synchronising switch board.

FIG. 191

When the phases of the two alternators correspond, the voltmeter indicates the standard E.M.F., and the lamp is fully incandesced. The second alternator is then instantly put in parallel with the first by the insertion of the main switch. The slightest inclination of one dynamo to get out of step with the other throws the work on the faster engine, and reduces its speed, so that one plant entirely controls the other.

The board shows alternators Nos. 2 and 4 coupled for observing the moment of synchronism when they are in synchronism and also in the same phase, that is to say, synchronously cophased. The lamp is at full brilliancy, and indicates the condition; the voltmeter indicates that they are not only in phase but that the incoming machine is also fully excited to the proper pressure.

Another indicator, by Everrett and Edgecumbe, is shown in Fig. 191 and is described as follows:—

Synchronising Induction Motor

The apparatus consists of a two-phase rotor and a two-phase stator, the rotor being fed by current from the busbars and the stator from the incoming machine, or *vice versâ*. Two rotating fields are thus produced, so connected that they will revolve in the same direction, and if they are rotating at the same speed the rotor will stand still. If the stator field be revolving faster than the rotor field the rotor will tend to follow it, or if the stator field is slower than the rotor field it will rotate in the opposite direction. This equality of frequency is shown by the pointer which the rotor carries ceasing to revolve; equality of phase is shown by the pointer coming to rest in a vertical position. It is thus possible to determine the moment of synchronism with the utmost accuracy, besides which it is at once evident whether the incoming machine is running too fast or too slow. In order to show this at a distance an arm is carried friction-tight on the spindle which uncovers one or other of two lamps (a red and a green), according to the direction of rotation. The lamp at the top of the case is an ordinary synchronising lamp, and can be used or not as required, but will be found useful as indicating to the driver at a distance whether he is nearly up to speed or not.

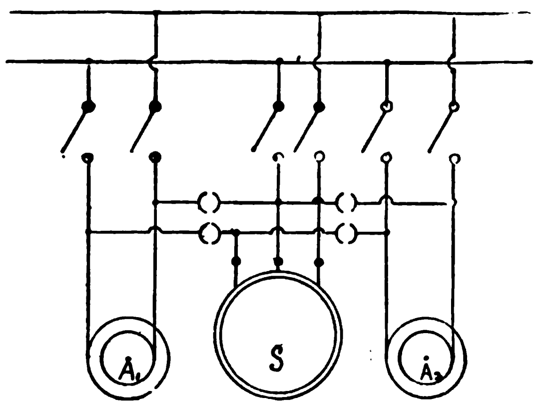


FIG. 192

The diagram, Fig. 192, shows the method of connecting up the apparatus, transformers being, for the sake of simplicity, omitted. The synchronisers are usually made for a voltage of 100. In the case of high-pressure systems the voltage must be reduced by means of step-down transformers. For this purpose the ordinary transformers can be employed.

By means of this instrument the largest alternators can be paralleled with rapidity and absolute safety even by a novice.

It is sometimes useful to find out the exact frequency of an alternating current: this can be done in several methods. One by Mr. A. Campbell is described as follows, and is illustrated by diagram, Fig. 193.

In the form shown, a magnetic or partly magnetic elastic strip V, which is free at one end and is acted upon by an electromagnet M carrying the current, has the length of its vibrating portion varied until the vibration is a maximum, by means of a sliding piece P actuated by a rack T and pinion U, which moves the vibrator

through a clamp N. The vibration number of the strip, and therefore the frequency, is indicated by a pointer connected with a pinion Y gearing with a rack X. In modifications, the strip may be fixed at both ends, a number of strips tuned to different frequencies may be used, and an auxiliary vibrator forming a rattling device may be actuated by the primary vibrator.

Another method used by the author many years ago consists in applying a little synchronous motor as a speed indicator. The speed divided by the number of pairs of poles, as we have seen, equals the frequency. Paul Lecour, a very clever electrician, invented a system of telegraphy in which the sending and receiving instruments

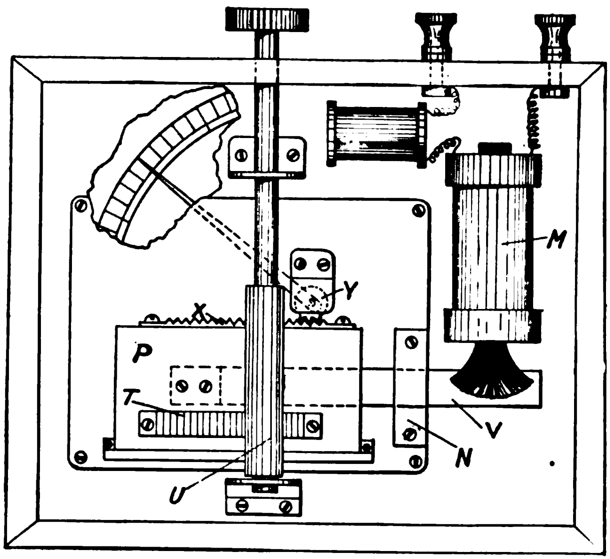


FIG. 193

required motors running synchronously. His currents were pulsatory currents produced by an electrically vibrated tuning-fork making and breaking a battery circuit. These currents were transmitted to the motors, and energised a coil shown in the figure with an iron wire core. In front of the one end of this core was pivoted a toothed iron wheel, as shown in Fig. 194.

On the top of this wheel is a wooden box carrying some mercury. This acts as a dash pot and greatly assists in maintaining a steady motion; for if the wheel suddenly received a greater impulse, the mercury slips and so retards the wheel, and, if this should lag slightly, the mercury tends to go on by its momentum and thus drags the wheel round.

In this case there is only one pole, and that is not reversed but intermittent; the speed multiplied by the number of teeth equals the

frequency of the pulsations, and, if a speed indicator is attached to it, the frequency can easily be found.

On the same principle motors, run by alternating current can be made of very simple construction to run synchronously. It was devised by one of the pioneers of the polyphase motor, Mr. Coerper. It is shown in diagram in Fig. 195. This motor has a bare star-shaped armature *a*, built up of iron plates, two neighbouring arms of which are subjected to the action of alternating magnetic poles.

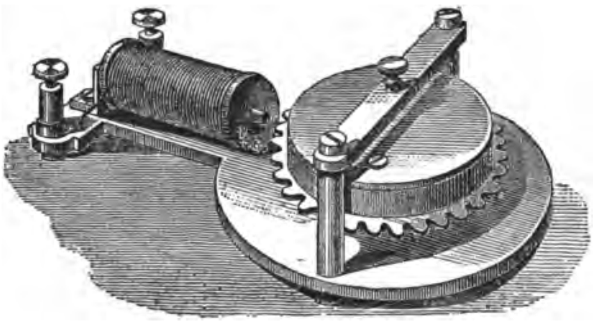


FIG. 194

The field magnets may have a closed magnetic field, and they may also be arranged inside and the star-shaped armature outside.

This type of motor could be made more powerful by increasing the poles in number, and is only useful for small powers such as are required for synchronous phase indicators or frequency tellers.

They are also interesting and easily constructed models for experimental working in the many cases wherein two pieces of mechanism at a distance are required to work at synchronous speed.

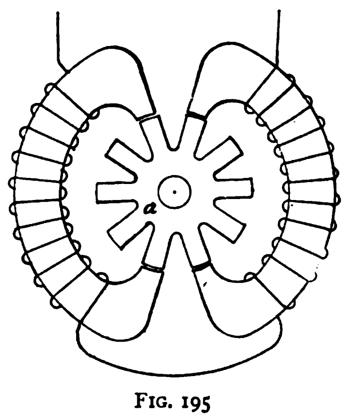


FIG. 195

It would, when combined with a speed indicator, make an excellent frequency indicator combined with a tachometer, as shown in Figs. 196 and 197.

An instrument very much required in polyphase working is one which would indicate exactly the difference in phase between two or three currents. No such instrument exists, and some trouble arises on polyphase circuits with motors due to the shifting of phases in polyphase circuits which are not balanced.

The impressed pressure impulses may succeed each other in proper order at the generator terminals; but, owing to self-induction and capacity effects, the currents may shift in phase considerably, so that, instead of receiving two currents in quadrature—that is,

one at a maximum when the other is at a minimum—two currents whose phase difference is unknown are received, and the motor fails to operate properly, and, if it happens to be on a municipal supply circuit, creates no end of trouble.

The same thing happens, but to a less extent, on three circuits having a phase difference of 120° impressed at the generator. There is a tendency, however, in this three-phase system to equalise the circuits, which does not exist in two-phase circuits.

Some municipal supply authorities, finding themselves committed hopelessly to a high-frequency alternating-current system, and thereby handicapped in motor work, have endeavoured to better their position by splitting the system into a two-phase one, but without much success, due to this want of balance between the two circuits.

It might be considered at this date futile to refer to magneto

FIG. 196

FIG. 197

machines—that is, machines with permanent magnets; but machines with permanent magnets have been useful in the past, and will no doubt figure to some extent always in electrical engineering. Because a thing has dropped for a time out of use, the scientific engineer does not conclude that its day is past. Nearly all recent improvements are only resuscitated things of the past—for instance, the steam-turbine. The modern turbines are merely the same, but better constructed turbines than those made and described fifty years ago. At that early time in engineering the turbine makers could not command the high quality of machine tools and materials at the disposal of present-day constructors, and which contribute so much to their successful operation.

Neither had they any high-speed machines to drive like dynamos, nor had they boilers which would carry steam pressures above fifty or sixty pounds, and condensers were not so perfect.

The self-exciting dynamo, of course, must always hold the first place as a generator or motor; but there are circumstances in which

the permanent field magnet is better, and one of these cases was for years the supply of current for lighthouse lamps.

In this case absolute reliability could not be depended upon with self-exciting machines. The brushes and commutator were for years a continual source of trouble, and required special skilled attention, which could not be provided in isolated lighthouses. To meet the case, M. de Meritans of Paris constructed his magneto alternator shown in Fig. 198, in which there is no need for a commutator, the current being taken off by a pair of slip rings. Many

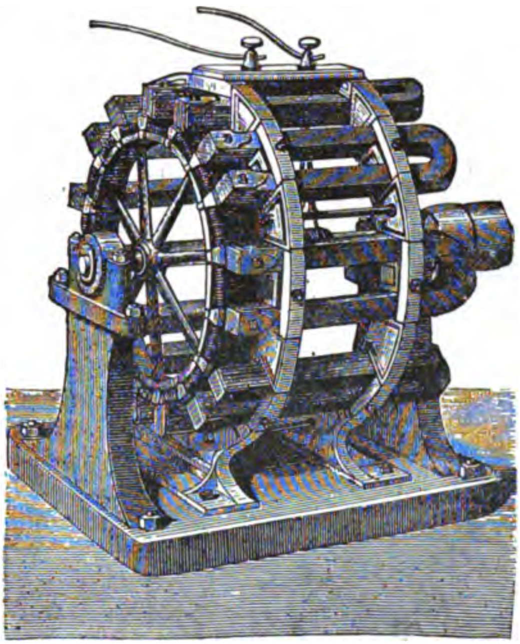


Fig. 198

lighthouse have been lighted for many years with these simple, reliable machines.

It will be noted that they could be made on modern designs for two-phase or three-phase currents, and to give a greater output than those constructed on this early design. Fig. 199 represents a magnet and part of the armature to an enlarged scale. Nowadays we would make this armature with slots in iron stampings, and wind it as a drum winding, and thereby obtain more out of it than De Meritans did.

A magneto like this could be used with great advantage in transmitting small powers from wind or water wheels in remote districts where little or no skilled attention could be obtained, a three-phase generator and a three-phase motor making an ideally simple transmitting apparatus.

These large steel magnets, however, cost a great deal more than an electro magnet of same power. Mr. Wilde of Manchester, the well-known pioneer, devised the first machines employing a combination of both magneto and electro magnets, the small magneto exciting a much larger electro magnet. The discovery of self-exciting magnets by Varley, Siemens, and Wheatstone led to the abolition of the magneto exciter, and the only commercial magneto which remained for long in use was the De Meritans lighthouse machine. Fig. 200 illustrates Wilde's machine. It is worthy of remembrance, although obsolete long ago, for it is the prototype of the very latest design of an alternator now before the author, in which there is a combination of magneto and electro magnets and great simplicity of construction and operation.

This self-exciting magneto-dynamo, Fig. 201, combination was specially designed by the author of this work for a simple ship-lighting plant, in which there are no collecting brushes, no commutators, nothing but two or three bearings to lubricate.

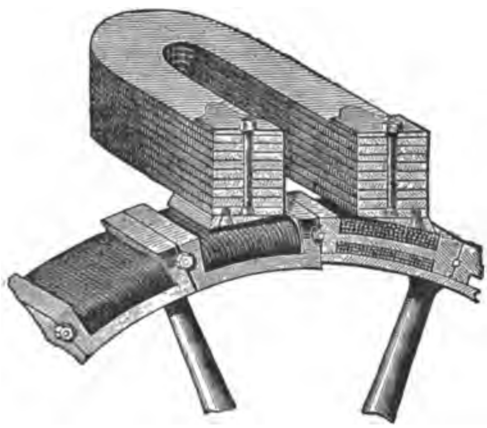


FIG. 199

The magneto of the smaller sizes is that generally used for telegraph and telephone work, with a laminated armature of the H type fixed on the end of a shaft, which also carries a field magnet rotating inside a fixed armature. The small exciting armature and the rotating field magnet are shown in the shaft in Fig. 203. They are both wound with wire of same gauge; any gauge may be chosen most convenient for winding, and the two coils joined through a hole in the shaft at the middle bearing to form a closed circuit. The field magnet rotates inside a laminated armature, built up and wound as a two- or four-polar stator, the coils being connected to the external circuit.

Twice in every revolution the field magnet will be excited fully by a wave of current from the small armature, thus producing a strong field cutting the stator coils and producing an alternating current therein.

The combination is shown in Fig. 201. It is one intended primarily for small installations where skilled attention is not available, and for small ship plants is the very thing required; it is also useful in country places where small water-power is available.

Magneto and Dynamo Combined

For larger machines the inductor type of revolving field is preferable, laminated, shown in Fig. 202 in diagram. It is difficult to laminate this form by disc stampings, but it is easy to build it of strip iron bent up into U shape

Fig. 204 shows one of the stator slots, with wires in place and a wooden wedge in the mouth of the slot to keep wires secure.

In connection with alternating-current experimental work it is of importance sometimes to know what the value of self-induction in a current may be. There are various methods described in electrical works for this purpose ; most of them require a Wheatstone bridge.

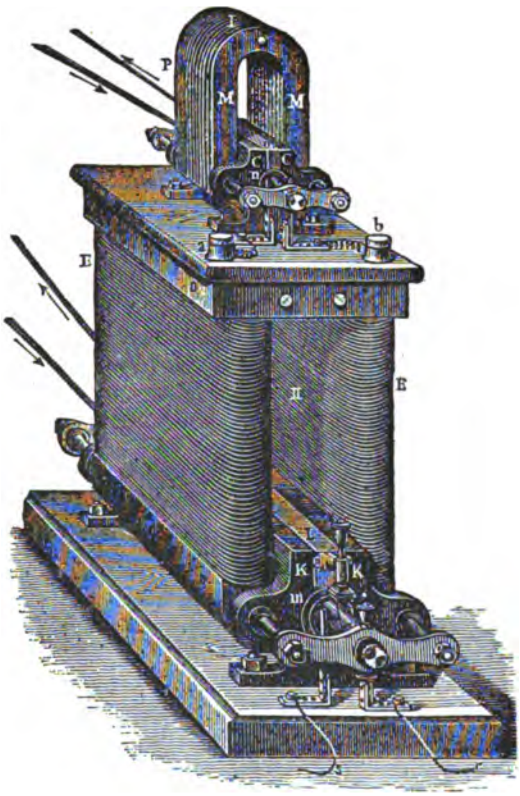


FIG. 200

The secohmmeter of Messrs. Ayrton & Perry is a practical instrument.

The secohmmeter as a whole consists of a box, Fig. 205, with a multiplying train of wheels driving commutators for reversing currents ; also a variable standard of self-induction, Fig. 206, against which we balance the unknown self-induction and thereby measure it. Messrs. Nalder Bros.' form is shown in Fig. 207. A coil of

wire, with any device for allowing the induction through it set up by another coil, is the feature of these standards.

Another type, Fig. 208, has self-induction coils adjusted to 10, 20, 30, and 40 millheurys, to be used by plugging as in resistance boxes. The instruments illustrated are those of Messrs. Nalder Bros.

This instrument is used with an ordinary bridge arrangement, for reversing the battery and galvanometer connections alternately, and thus commutating the self-induction "kicks" into a steady unidirectional deflection. When used with a variable standard the self-induction to be measured is put in the "X" arm of a bridge and the standard in the "R" arm. A steady resistance balance is first obtained. The handle is then turned, and the above-mentioned steady deflection reduced to zero by setting the variable standard.

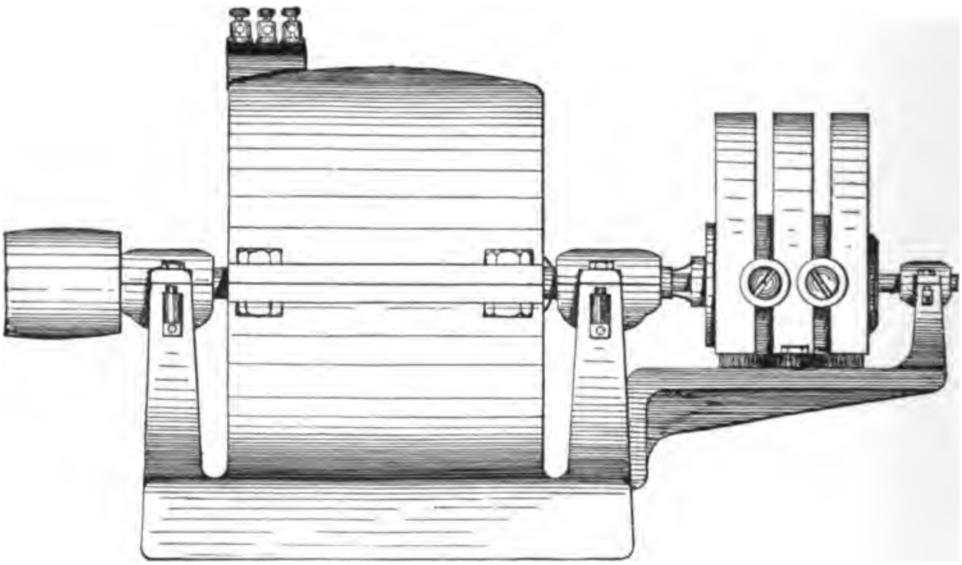


FIG. 201

Standards of fixed values can be used in series with the variable one to increase the range. Multiplying and dividing ratios in the bridge can be used as in resistance work. The present instrument is of our own design, and is made entirely of metal and ebonite, with a bevelled glass top. The commutators and brush holders are outside the brass case, at opposite ends of the same spindle. The plate carrying one set of brushes is arranged so that it can be rotated through an angle up to 90°, and the lead thus easily varied. The handle fits either of two spindles for high or low speeds. 80 alternations a second can be easily obtained by hand, as the instrument now runs very lightly.

The secohmmeter is also extremely useful for capacity and other similar measurements.

Reference has been made to all the more interesting types of machines, especially to these odd types—the Homopolar continuous-current dynamo, the various alternators, the alternating

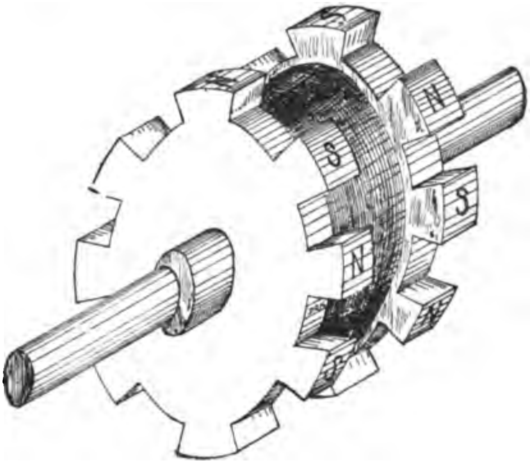


FIG. 202

series motor for traction purposes, the magneto machines, and the combination of magneto with dynamo alternator, purposely to divert the student's attention to the fact that what is considered good practice and the *ne plus ultra* of to-day may still be improved upon. From the manner of writing and teaching by scholastic

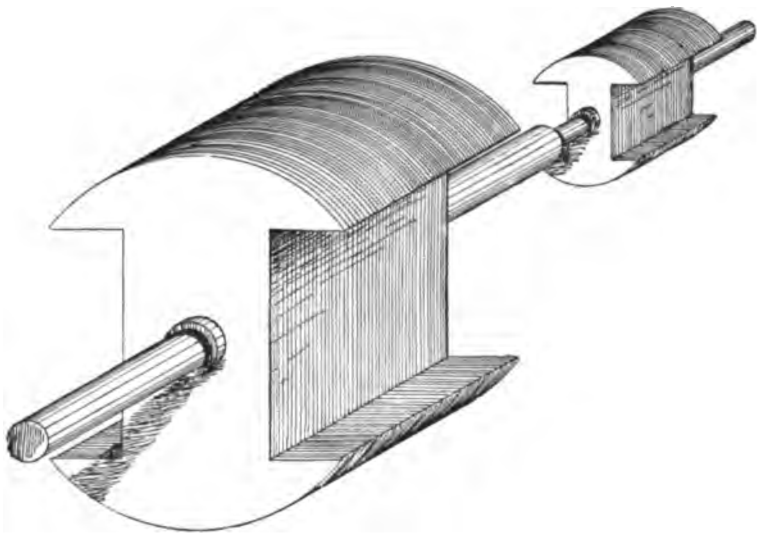


FIG. 203

authorities the student comes to practical work too much imbued with the idea that the engineering and machinery he has been shown as the very best in practice is all final, quite perfect, and

no further advance can be made. A very mistaken idea. The engineer who is to become a leader has no such notions. To him inquiry into every peculiarity of construction and action in machines is of interest; and he does not without criticism accept the fact that, because somebody has adopted a certain machine or system of machinery, such a fact proves it to be the best for the purpose.

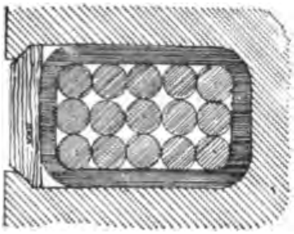


FIG. 204

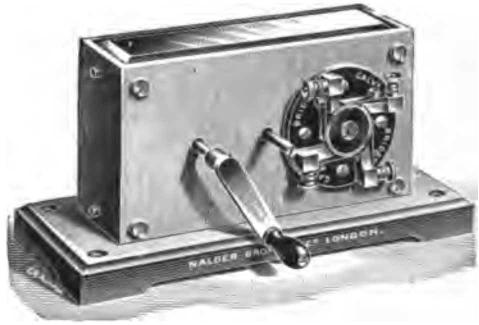


FIG. 205

I have heard students say that they were born too late; everything had been discovered before they came on the scene—that also is a mistaken notion. As a fact, very little has been discovered, and an immense field of undiscovered things is still before us. An eminent inventor many years ago shut up his electrical laboratory

FIG. 206

with the declaration that nothing more remained to be found out about electrical engineering; nevertheless, there has been some important work done and discoveries made since then in induction motors, X-rays, space telegraphy, and so on.

To the majority of students the simple experiment whereby

nitric acid is produced by passing an electric current through air in the form of a spark or arc, has no significance whatever, except as a fact that oxygen and nitrogen can be so combined directly in the atmosphere. But to some minds this fact opens up trains of thought, such as that nitrogen compounds are essential for the life of plants and animals; that as ordinarily found these compounds are not too plentiful; that in the atmosphere nitrogen exists in abundance and costs nothing. Hence, if this simple process could be enlarged and improved, nitrogen compounds could be produced from the atmosphere cheaply; the outcome of this cogitation is a practical method of producing nitrogen compounds electrically.

Same with most other inventions. To most electricians Hertz oscillations and detectors were well known and interesting, and nothing more; but to Mr. Marconi they suggested space telegraphy, now an accomplished fact.

There is much more progress made in engineering by the

FIG. 207

FIG. 208

adaptation or improvement of old systems, apparatus, and devices than by new discoveries. New discoveries are few and far between, and, naturally, the possibilities of new discoveries must become less and less in all sciences; but the adaptation of the knowledge of heat, light, magnetism, electricity, and mechanics to useful purposes opens up a wider field of operation immediately following every improvement.

It is therefore better for the student, after mastering the sciences of physics and mechanics, not to spend too much time in studying what happens to be at the moment called best practice, but to consider all the other possible methods and applications to the same end, and so exercise his mind on the problems connected therewith.

Continuous-current motors and dynamos are gradually becoming standardised, and their manufacture is becoming also quite a common phase of engineering works; in fact, the shops they are made in cannot be distinguished from a shop making machine tools, except that it has a wire-winding department. The only interesting problem in their construction is to find out how to produce them at the lowest possible cost. the solution of which depends partly on the design of

the machine, and a great deal upon the equipment and organisation of the factory producing them. Small motors of simple but substantial design at reasonable prices have not received the attention they should have had. There is an immense field of usefulness for motors under three horse-power to take the place of belts and shafting. They must be placed right up to the work to be done; the interposition of a shaft or belt or two between motors and their work in most cases counterbalances all the advantages claimed for electric transmission of power. No doubt there are plenty of small motors in the market, some cheap, some good, some otherwise. But I have not yet come across the entirely satisfactory small motor; the cheap ones are no good, the good ones too dear. It is chiefly due to bad design, this state of affairs. A design which one can afford to adopt for manufacture of motors above three or five horse-power is seldom possible for smaller machines at a profit. The subdivision of the power into small units in factories is the secret of the success of electrical transmission, hence the importance of the small motor. "Each tool, each machine, its own motor," is the successful system.

In transmission of power, next to the small motor, the isolated or private generating plant is of importance. The cheap supply of electrical energy from central generating stations for power purposes has yet to be realised. At present—and for a long time to come—it has not got beyond rather hazy proposals for crude and impracticable schemes. The internal-combustion engine, when once provided with a simple reliable gas-producer, coupled to a good continuous-current generator, will prove hard to compete against by any large distribution scheme.

Alternating-current work is not so far advanced as continuous current, and will take some time to settle down to standard machinery. The developement of the single-phase motor is still going on, and may result in something to compete with the continuous-current motor.

In addition to the progress made by improvements in details and the adaptation of old ideas to modern uses, mostly due to practical electrical engineers, there is the progress made by purely scientific research, slow but sure. Although this pursuit has of late attracted fewer workers than it used to do before electrical engineering became a commercial profession, it is still going on, chiefly in Germany. Scientific research does not pay the searcher.

There are many problems awaiting attack in electrical work, most of which can only be solved by patient scientific work without much prospect of monetary reward—the greatest problem of all being the direct generation of electric pressure from the fuel in which the energy is locked up.

END OF VOL. III.

1.-